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Geology of a volcanic complex on the south flank of Mount Jefferson, Oregon

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The volcanic stratigraphy and petrography is described for a 46 km^2 area on the southern flank of Mount Jefferson in the north-central part of the Oregon High Cascades. Here, volcanic processes have been active throughout Quaternary time, resulting in complex stratigraphic relationships. In addition, three formerly recognized glaciations and a two-phase period of neoglaciation

have eroded the terrain, depositing tills in contact or interstratified with the volcanic units. Collectively, these processes and the resulting deposits are characteristic of High Cascades development.

The volcanic products, with a minimum aggregate thickness of 3600 m, originated from twenty-one identified or inferred eruptive centers within and adjacent to the study area. The oldest (Minto lavas) comprise the earlier, partly coeval lavas of Hunts Cove and Cathedral Rocks, volcanic rocks underlying North Cinder Peak, and the later, coeval Sugar Pine and Bear Butte volcanoes. The Minto lavas were eroded by Abbott Butte glaciation and followed by eruptions of North Cinder Peak, an intracanyon flow and a small domal feature north of Cathedral Rocks, and the Goat Peak assemblage. During much of this period the formerly recognized Main Cone sequence of Mount Jefferson developed, but probably began prior to Abbott Butte glaciation. Following the next (Jack Creek) glaciation, Mount Jefferson produced its Second Stage sequence at about the same time 'Patsy Lake' volcano erupted. These events were followed by emplacement of The Table, consisting of three similar but distinct eruptive features. After these events, the area was eroded by the two-phase Cabot Creek glaciation. Ensuing volcanism consisted of Red Cinder Cone, the partly coeval Forked Butte and Horseshoe Cone volcanoes, and 'Hodge Cone' - the youngest volcano in the study area. The youngest glacial episode (Jefferson Park neoglaciation) followed shortly thereafter, affecting primarily the cone of Mount Jefferson. With waning volcanic and glacial activity, mass wasting became dominant, producing extensive deposits of surficial debris.

The volcanic products consist predominantly of lava flows with subordinate eroded plugs and localized pyroclastic deposits. The Minto lavas formed broad, coalescing shield volcanoes of microporphyritic basaltic andesite. Some of these produced smaller composite volcanoes near their summits during later explosive phases. Subsequent volcanism was more localized and, morphologically and petrographically, more diversified. Collectively, the rocks became more phaneritic and silicic until late Pleistocene and Holocene time when volcanism became mainly characterized by tephra cones and commonly associated lava flows of moderate extent. These recent volcanic rocks also show a compositional 'regression' to basaltic andesite.

The Table is composed of porphyritic, hornblende intermediate andesite, and is interpreted as three coalescing domes showing some attributes common to stiff lava flows. The middle Table formed first and was partly overridden by the later, coeval south and north Tables. Evidence for their domal origins comprise: 1. circular to oval outlines; 2. flat surfaces; 3. abrupt, steep sides; 4. upward diverging flow units; 5. concentric, arcuate surface lineations; 6. concentric, steeply dipping flow layering (foliation); 7. oxidized surface rocks; 8. limited lateral flowage; and 9. alignment along a presumed north-south fissure. The intermediate silica contents of the Tables suggest factors responsible for their formation to be more inherently physical than chemical in nature.

Some evidence for tectonic influence on local volcanism consists of northwest-trending dikes in Bear Butte and Sugar Pine volcanoes, and the occurrence of Horseshoe Cone along the same trend. This alignment parallels regional northwest-oriented structural lineaments which may intersect the High Cascades lineament in complex ways, forming zones of crustal weakness conducive to intensified volcanic activity.

GEOLOGY OF A VOLCANIC COMPLEX ON THE SOUTH FLANK OF MOUNT JEFFERSON, OREGON

by

BRIAN LEE GANNON

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INTRODUCTION

Purpose and Procedure

The primary intent of this work was to (1) map and describe the volcanic units on the south side of Mount Jefferson, in the north-central High Cascade Range of Oregon, (2) determine the stratigraphic sequence of these units, and specifically (3) to account for an unusual flat-topped volcanic feature, The Table, and relate it to the surrounding geologic units.

A total of forty-three days was spent in the field over a four year period: September 15-24, 1971; October 14-18, 1972; August 22-September 10, 1973; and August 7-14, 1974. Due to the remoteness of the area and lateness of the season, roughly one-third of this time was spent hiking to and from the area, preparing and breaking camp, and waiting out storms.

Geologic mapping was done at a scale of 1:12,000, using enlarged portions of U. S. Geological Survey 7.5-minute advance maps as a base. Geologic intrepretation was facilitated by the use of black and white aerial photographs at scales of 1:12,000, 1:15,840 and 1:62,500. In addition, a set of low altitude, north-oriented oblique photos was helpful in viewing the units from a different perspective.

Final tracing of the volcanic units and classifying of rocks was primarily contingent on whole-rock silica content determined by fusion analysis. Subsequent silica determinations and petrographic examinations were made with a Zeiss refractometer and a Zeiss polarizing microscope. The silica values obtained in this study were calibrated against four pre-determined samples donated by Dr. R. C. Greene of the U. S. Geological Survey. Remanent magnetism polarity of oriented rock samples was determined by portable flux-gate magnetometer.

Description of Area

This study encompasses a 46 km^2 area straddling the crest of the Cascade Range immediately south of Mount Jefferson (Figs. 1, 4), in the northeastern corner of Linn and the west-central part of Jefferson Counties. Except for the northeastern corner, which is under the jurisdiction of the Warm Springs Indian Reservation, the study area lies wholly within the Mount Jefferson Wilderness. The map base incorporates the southeast corner of the Mount Jefferson, southwest corner of Lionshead, northwest corner of Candle Creek and north-east corner of Marion Lake 1961 U. S. Geological Survey 7.5-minute advance quadrangles (Fig. 4).

The area is accessible from both the east and west sides. Entry from the west is by way of the 14 km-long Pamelia Lake-Hunts Cove Trail No. 3439, off Forest

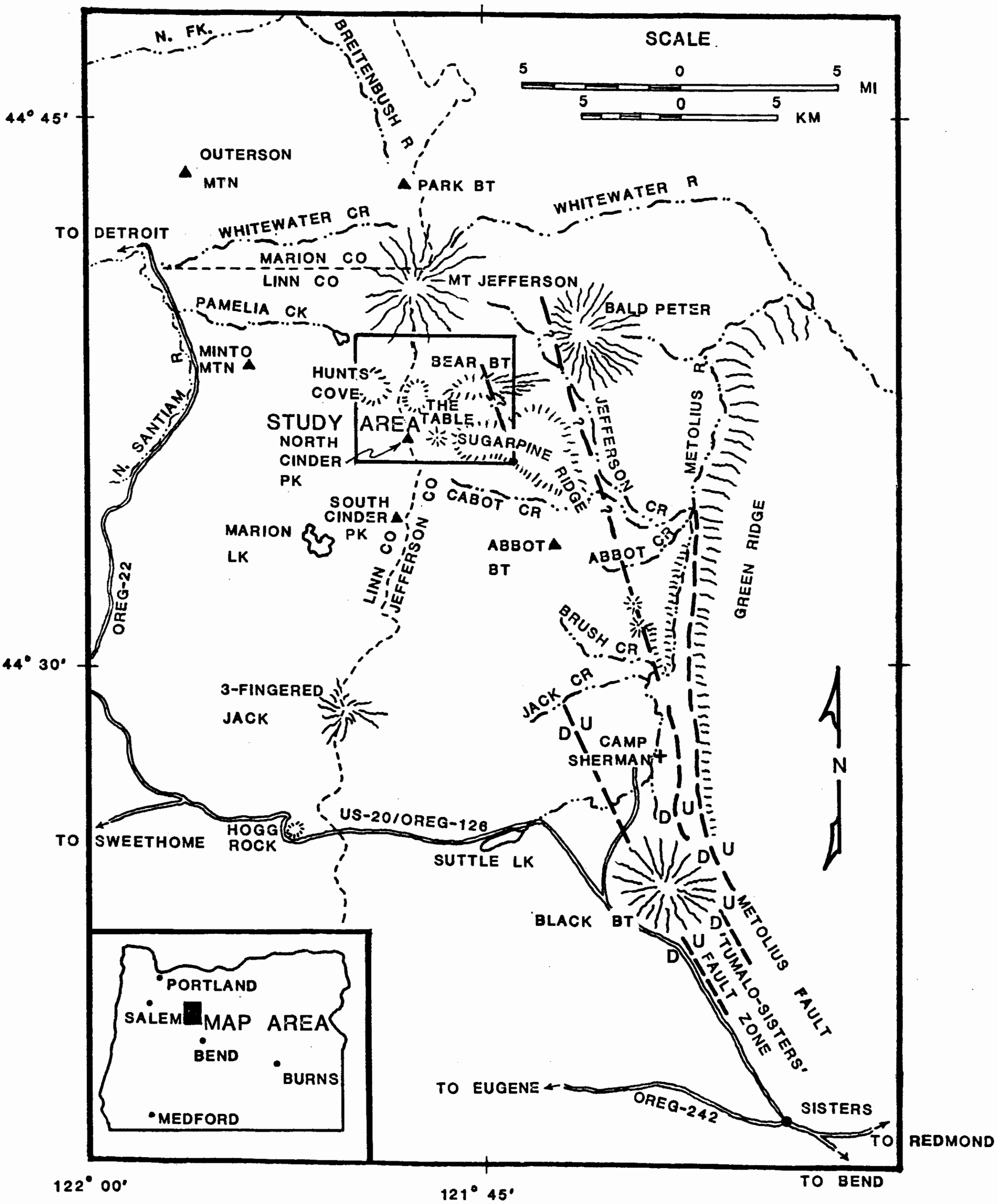


Figure 4. Location and general tectonic map of the Mount Jefferson area. Base map, Bend, Oregon Quadrangle 1:250,000, Sheet NL-10, 1964. Tectonic data from Peterson and Groh (1972), Scott (1974), Hales (1974) and Gannon (1978).

Service Road 109, 21 km south of Detroit on Oregon Highway 22. From the east, it is 16 km via the Jefferson Lake Trail No. 66 which leaves Forest Service Road 1154, 14.5 km north of Camp Sherman. These secondary roads are impassable during the winter months due to heavy snowfall.

The area is rugged with local relief of about 700 m (from Jefferson Lake to Goat Peak). Average elevation of the study area is about 1650 m. The large glaciated composite volcano of Mount Jefferson (3150 m) dominates the landscape to the north, and rises 1350 m above its surroundings. The area is entirely volcanic in origin, and has been modified intensely by multiple alpine glaciations. The oldest rocks now stand as castellated ridges and spurs radiating outward from eroded volcanic centers, separated from each other by U-shaped valleys of various dimensions. Glacial cirques abound on the higher peaks and ridges, and some of the larger, more ancient ones have been subsequently filled with volcanic features such as The Table within the large cirque east of Cathedral Rocks (Fig. 5). Many sheltered cirques and valleys contain patches of ephemeral ice and snow. The only permanent ice occurs on Mount Jefferson in the form of numerous glaciers covering about 6 percent of the mountain's surface. The younger post-glacial (Holocene) volcanoes have distinct, well-preserved appearances.

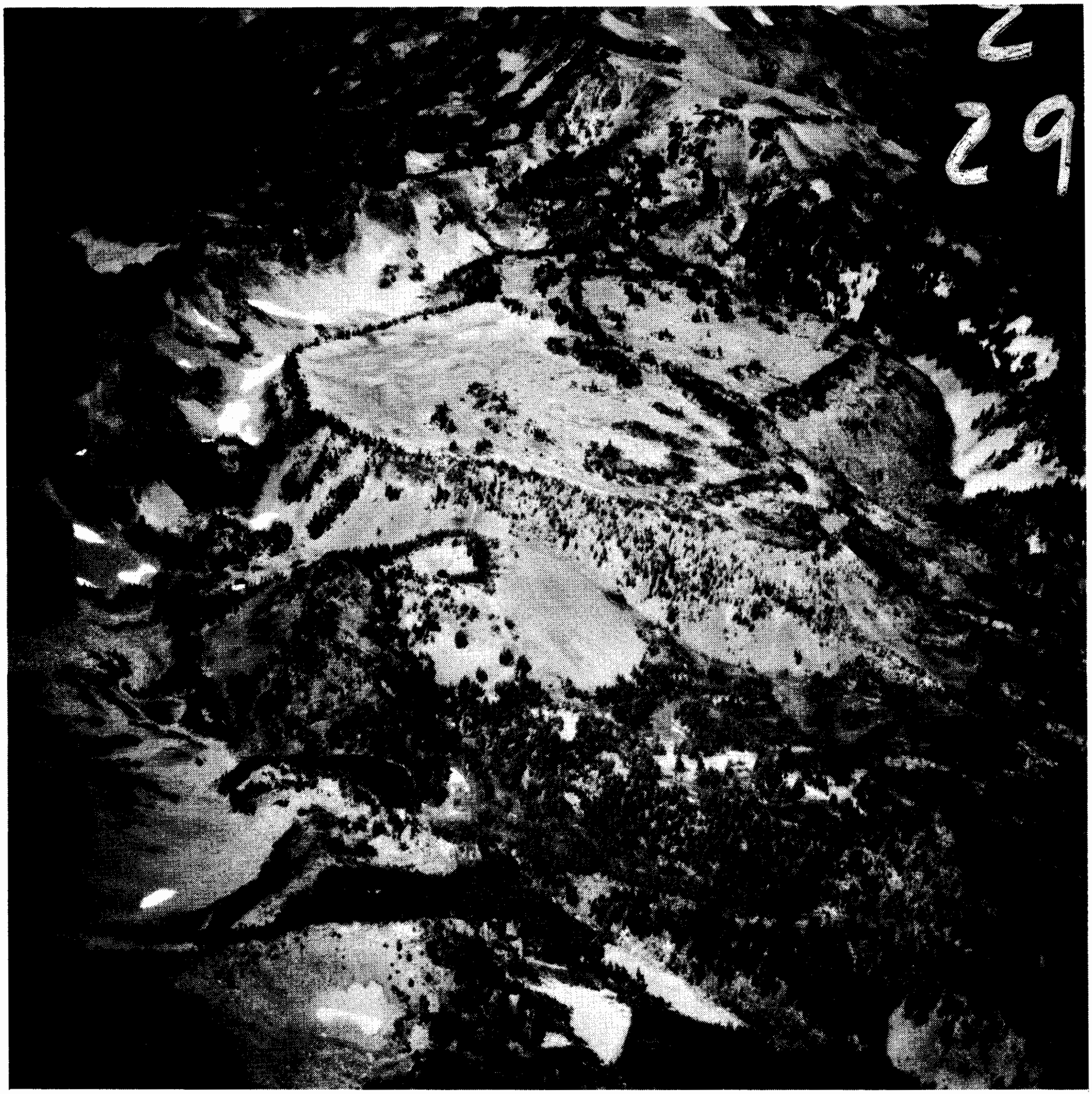


Figure 5. Oblique north view off The Table (center of photo), interpreted as three large coalescing, endogenous domes. The "south" Table is towards the front. They occupy a cirque cut by Jack Creek glaciation located on the south flank of Mount Jefferson, rising in the background. The Cathedral Rocks make up the glaciated ridge to the left, within which a pre-Table age intracanyon flow (Qil) is seen in the northern part. A Recent tephra cone ("Hodge Cone") lies on the south flank of the south Table and partially buries an older plug which produced the "Patsy Lake" lavas. The flows exposed in the cliffs in the left foreground are part of the North Cinder Peak shield volcano.

Many lakes and streams occupy the area, and tend to be controlled by the contacts between lava flows. Some lake basins (e.g., Table Lake) have been formed along flow contacts scoured by glaciation. The general drainage direction probably reflects the original flow direction of the lavas which trended mainly east and west away from the Cascades crest. The western side is presently drained by the North Santiam River 11 km to the west, and the other side, including most of the study area, by the Metolius River, 14.5 km to the east (Fig. 4). Numerous small lakes also occur as tarns, as in Hunts Cove, and some have been created by localized debris flow and ice-kettling. Two small lakes formerly occupied "Bear Meadows" and Hole-in-the-Wall Park, south and west-northwest, respectively, of Bear Butte, but through alluviation these now exist only as small, semi-stagnant ponds.

Bedrock exposures in the higher areas are generally abundant and are only locally covered with patches of evergreen trees and shrubs. In the lower valleys, however, the vegetative cover is fairly dense, concealing outcrops and rendering travel difficult. Much of the ground surface is mantled with glacial till and glaciofluvial deposits, and the slopes and narrow valleys are covered with talus.

Geologic Setting

The Cascade Range is a linear, north-south mountain belt extending 1100 km from Mount Lassen in California to Mount Garibaldi in British Columbia. Nearly all of the range is composed of Cenozoic volcanic and volcaniclastic rocks.

In Oregon, the range, as divided by Callaghan (1933), consists of two roughly parallel belts named the Western Cascades and the High Cascades. The older Western Cascades are mid- to late Tertiary (5 to 40 million years) in age, and are structurally deformed, highly eroded, and locally propylitized (Peck, and others, 1964). Hales (1974) has shown that rocks similar in age, lithology and chemistry to this sequence also occur in the Green Ridge area to the east (Fig. 4).

The High Cascades form a complex constructional platform, composed along its entirety of several thousands of volcanoes, which unconformably overlie the Western Cascades of Oregon. Fragmental rocks, laharic deposits and intrusions are locally important, but the preponderance of the rocks erupted as lava flows of chiefly basaltic andesite and andesite. Primarily the High Cascades consist of a thick aggregate of coalescing shield volcanoes capped by a number of distinct composite (strato) volcanoes. The volumetric extent of these younger cones amounts to only about 20 percent of the approximate 1280 km^3 of material produced by the older shields in the Bend, Oregon region (Sutton, 1974, p.102). In contrast to the older rocks to the west, the High Cascades are largely unaltered and structurally undeformed, and despite the effects of multiple Pleistocene glaciations, much of the original form is preserved.

In accordance with their general structure and age, the High Cascades have more recently been subdivided into an "early" or "older" High Cascades sequence and a "younger" High Cascades sequence (Taylor, 1968, p. 3; Hammond, 1976, p. 82, 83), each composed of numerous volcanic assemblages. Like many belts of andesite volcanoes, the High Cascades may lie along a volcano-tectonic depression (Allen, 1965; Hales, 1974).

Previous Geologic Studies

The first geologic observations of the Mount Jefferson area were made by Russell (1905) who noted the recessional characteristics of the glaciers on the east side of Mount Jefferson. Hodge (1925) later elaborated on the glacial history of the mountain, proposing three periods of Pleistocene glaciation. In addition, he produced the first detailed topographic map of the area and, with emphasis on physiography and petrography, intrepreted the Cenozoic volcanic geology of Mount Jefferson and its vicinity.

Callaghan (1933) divided the range into an undeformed "High" Cascades and an older "Western" Cascades sequence which, in confirmation of the early suggestions of Russell (1897), he believed to be separated by a profound unconformity.

Thayer (1937) described the petrography and petrology of both High and Western Cascades lavas from an area extending from Detroit to The Cascade crest which he related to several structurally distinct series, unconformably separated from one another. Those from the High Cascades he named, in ascending order, the "Outerson series", the "Minto lavas", the "Ollalie lavas" and the approximately coeval "Santiam basalts". He also noted that the Minto lavas formed from large coalescing shield volcanoes which constituted the main bulk of the basal High Cascades platform. Later, Thayer (1939) studied the structure of the Western Cascades and related it to the younger lavas to the east. He also established a three-phase glacial sequence for the Mount Jefferson-North Santiam River area which he correlated with the drift sequence of the Sierra Nevada.

In his regional map of the central High Cascades, Williams (1957) mapped two Holocene intracanyon lava flows which border Sugar Pine Ridge within the present study area (Fig. 4). More extensive reconnaissance mapping was done by Walker, and others (1966) within the Mount Jefferson Wilderness as part of evaluating the mineral potential of that area. Several of the volcanic units involved in the present study were mapped and described at this time. Two years later, Greene (1968) described the petrography and petrology of a suite of High Cascade rocks from the Mount Jefferson-Three Fingered Jack area. Silica content, determined by fusion analysis, was used as the main independent variable in classifying these rocks. Also in 1968, McBirney discussed the petrochemistry of Cascade andesite volcanoes, dividing the lavas into two types, using Mount Jefferson and the South Sister as prime examples. His study included seven rock analyses for the Mount Jefferson area, and a comparison of AMF variation diagrams for twelve High Cascade volcanoes.

In the early nineteen-seventies, several studies were made of both trace and major element composition of rocks from the Mount Jefferson area. The first study was by Steinborn (1972) who analyzed a number of samples for trace element concentrations from Mount Jefferson, Mount Hood, Mount Shasta and the Three Sisters. Condie and Swenson (1974) measured both major and trace element concentrations of rocks from Mount Jefferson, Mount Rainier and Mount Shasta in order to investigate compositional differences and similarities between the respective eruptive sequences.

Sutton (1974) described the petrography and petrology, including trace element geochemistry, of a suite of rocks from the Mount Jefferson area. He also mapped the geology of the mountain and described a two-phase eruptive history.

Scott (1974, 1977) gathered detailed evidence of three major Pleistocene glaciations and a period of neoglaciation in the Metolius River area, including Mount Jefferson. He also mapped numerous volcanic deposits which he relegated to the interglacial periods as formations. Several of these volcanic units lie within the present study area.

Hales (1974) described the geology of the Green Ridge area, which includes the distal part of an intracanyon flow originating from the east within the area mapped here. In his study, Hales established the age of the rocks and faulting by radiometric dating techniques, and described the petrographic and petrologic characteristics of the rocks.

ANALYTICAL PROCEDURE

Refractive Index Determinations (Rapid Fusion Technique)

The rock classification employed in this study is based on both quasi-chemical and petrographic characteristics. The first involves the determination of silica contents by measuring the refractive indices of artificially fused glass beads derived from the rocks.

The correlation between chemically determined silica contents of natural volcanic glasses and their refractive indices, specifically an inverse relationship, was first noted by George (1924). This work was refined by Mathews (1951a) by artifically fusing rocks to a glassy state, thereby reducing such variables as water content and establishing a uniform oxidation state for iron. Mathews also noted that volcanic rocks from different petrologic provinces yielded substantially different silica - refractive index curves. This observation has been explored in greater detail by Huber and Rinehart (1966) who also stressed the importance of establishing specific curves for individual, petrologically related suites.

This technique is attractive because of its facility and economy, and under controlled conditions, yields results well-within 3 percent of the actual silica content of the whole rock. Callaghan and Sun (1956), Shilov and others (1958), Wargo (1960), Kittleman (1963), Rinehart and Ross (1964) and Greene (1968), among others, have successfully employed this technique to both characterize and correlate volcanic rock units.

The fusion process used in this study follows the methods of Wargo (1960), Kittleman (1963), and Rinehart and Ross (1964). All measurements were made at about 25°C using a stage-mounted Zeiss refractometer with a cell sensitive in the range of n 1.3 to 1.7. A sodium light filter was used throughout the process to help equalize effects of dispersion. Refractive indices were determined to within $\pm$ 0.001. Preliminary reliability of the technique was determined by crushing a glass slide, and comparing the refractive index of the shards against that of a fused bead of the same material, as recommended by Kittleman (1963). There was no detectable difference in the two resultant n values.

A total of 126 rock samples were selected for fusion analysis (Appendix) which, except for Mount Jefferson, represented all the recognized major volcanic units within the study area. Four of these samples are from tephra deposits. Location of these and other samples are shown in Figure 3. A small 's' (denoting silica) follows the sample numbers of those rocks whose silica contents were determined by fusion analysis.

Silica Determinations

Refractive indices of the whole-rock fused beads were converted to percent silica using the curve established by Greene (1968, p. G8), and reproduced in Figure 6. Greene's curve was determined by plotting silica contents of eight chemically analyzed rock samples from the Mount Jefferson Wilderness area against the refractive indices of their fused beads. The resulting variance between the refraction-determined silica contents, rounded to the nearest half percent, and the chemically determined values ranged from 0.1 to 1.9 percent, with an average departure of only 0.5 percent.

To further insure reproducibility of results for this study, present refractive index - silica values were checked against four previously analyzed samples donated by R. C. Greene: MJW-11, MJW-21, MJW-105 and MJW-73. The refractive indices of these range from 1.590 to 1.510 (Greene's) and in no instance was there a departure of more than $n \pm 0.002$ in the results (Fig. 6).

The relative distribution of refractive index measurements from the study area, Greene's included, is shown in Figure 6. With the aid of the curve, these

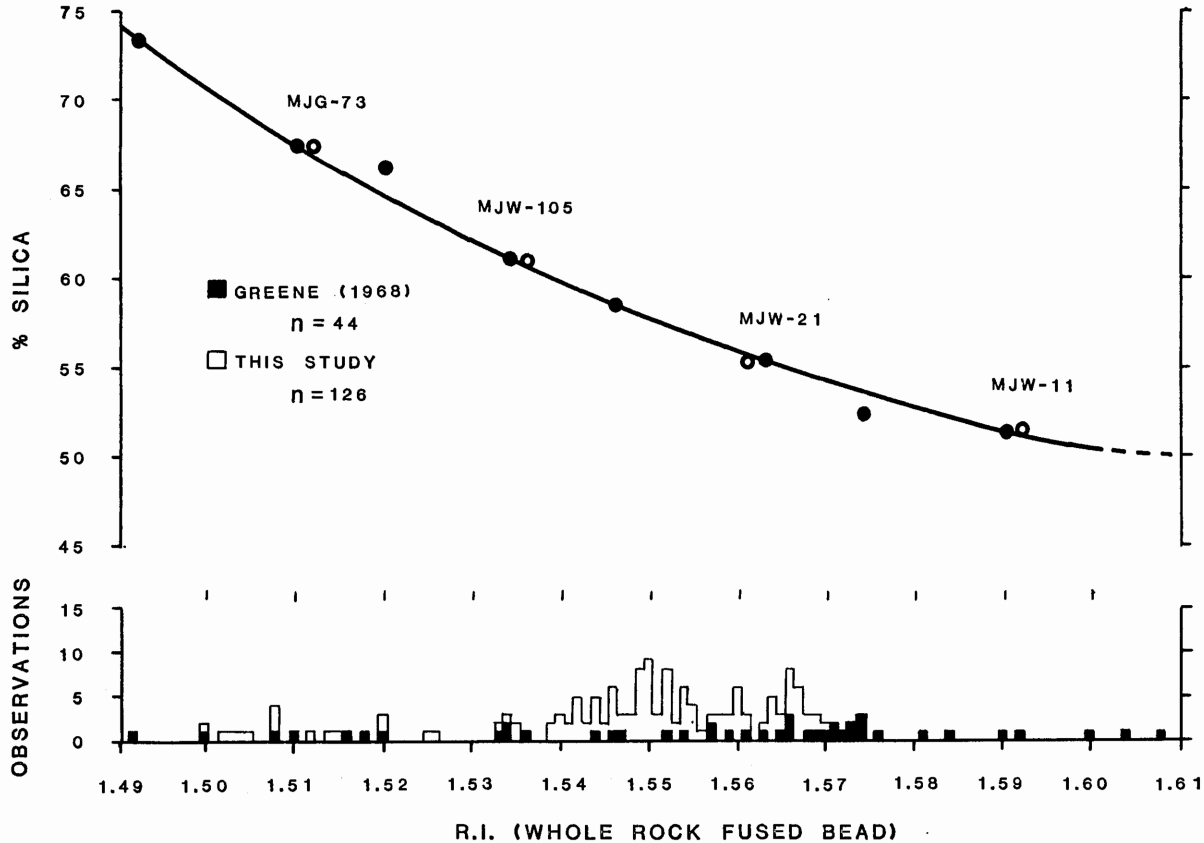


Figure 6. Distribution of refractive index determinations for 170 rocks from the Mount Jefferson area compared with the related silica curve established by Greene (1968). Open circles show refractive index values recalculated from Greene's samples (labelled) as controls for this study.

values (Appendix) were converted to the nearest quarter percent silica. Although the apparent + 0.5 percent accuracy of the curve may not justify rounding to this degree, it was done in an attempt to gauge the efficacy of the technique in distinguishing and correlating rock units in a detailed manner. This approach does not yield silica values which deviate substantially from chemically determined values rounded to the nearest half percent. Furthermore, comparison of values of the eight chemically analyzed samples of Greene (1968) and his corresponding curve determinations yielded about 0.05 percent greater compatibility by rounding to the nearest quarter percent.

Petrographic Techniques

A total of 280 representative rock samples were collected from the study area (Fig. 3). Of these, 49 were selected for thin-sectioning. Modal point count data and other rock characteristics, plus data from relevant specimens of Greene (1968), for 25 thin sections are given in Tables III-XV. For each thin section, 1000 point counts were made of the primary minerals as well as the important accessory and alteration minerals.

Phenocrysts (grains larger than 0.1 mm) were distinguished according to the criteria outlined by Schminke (1967, p. 1402): 1. crystals showing resorbtion; 2. crystals containing abundant inclusions; 3. crystals forming glomerocrysts; and 4. crystals forming the coarse grained fraction of a statistically bimodal grain size distribution. Minerals between 0.1 and 1.0 mm in size are designated as microphenocrysts.

Phenocryst density is defined by the following terms: aphyric, less than 3 percent; sparse, 3 to 10 percent; moderate, 11 to 20 percent; dense, 21 to 30 percent; and extreme, greater than 30 percent of the total rock volume. Among cumulophyric rocks, a subjective density estimate is made by using the terms, strong, mild and weak to respectively indicate, more than half, about half, and less than half the phenocrysts occurring as glomerocrysts. The terms, hiatal and seriate (Moorhouse, 1959) are used to indicate the degree of grain size biomodality between phenocrysts and groundmass components.

Anorthite content of plagioclase (phenocrysts and microlites) was determined by methods described by Tobi and Kroll (1975).

Rock Classification and Nomenclature

The rock classification scheme used here is basically descriptive and, with minor alterations in terminology and silica ranges, is similar to those employed by Greene (1968) and Sutton (1974). Silica content is taken as the primary independent variable against which other rock variates are compared. The base for silica distribution incorporated 217 rock silica values from the Mount Jefferson area. This population includes the 126 values established here by fusion analysis and an additional 91 values taken from Thayer (1937), Greene (1968), McBirney (1968b), Hales (1974) and Sutton (1974).

Classification parameters were established by synthesizing the results of 87 modal analyses from the Mount Jefferson region: 44 from Greene (1968); 1 from McBirney and 17 from Sutton (Sutton, 1974); and 25 from this study. For each, total volumetric percentages of plagioclase, augite, hypersthene, olivine and hornblende were plotted with respect to silica content (nearest quarter percent), giving rise to the distributions shown in Figures 7 and 8. This data is graphically summarized in Figure 9, showing <u>relative</u> volumetric mineral abundances for each class.

Rock class division were accordingly determined by placing silica content partitions in correspondence with major relative changes of mineralogic distributions, in a best-fit manner (Figs. 7, 8, 9). These partitions approximate, within a few percent, the limits established by other investigators who have classified rocks of the Cascade Range by various means.

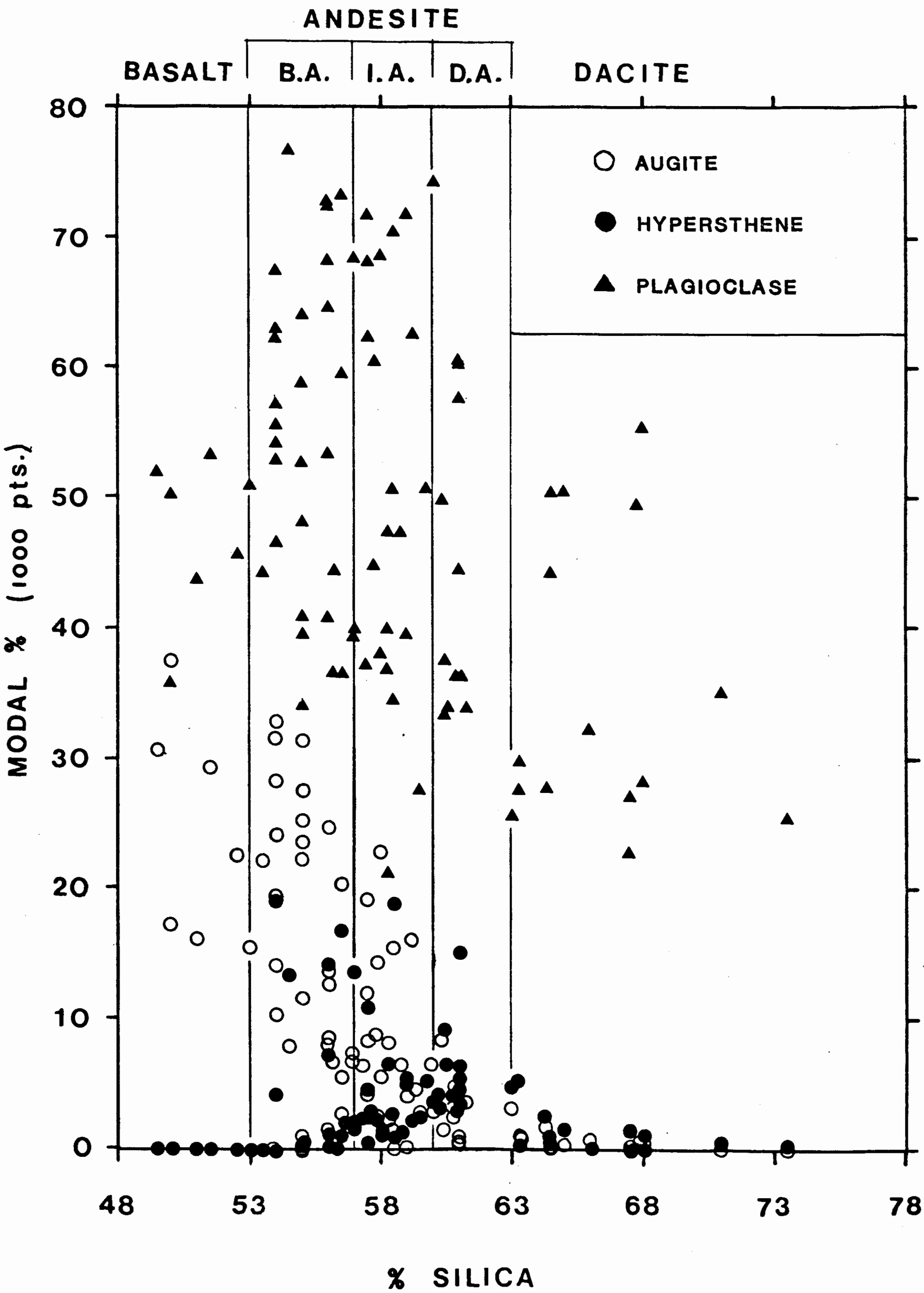


Figure 7. Distribution of modal plagioclase, augite and hypersthene versus silica content for 87 rocks from the Mount Jefferson area. Sources: Greene (1968), McBirney (1968), Sutton (1974) and this study.

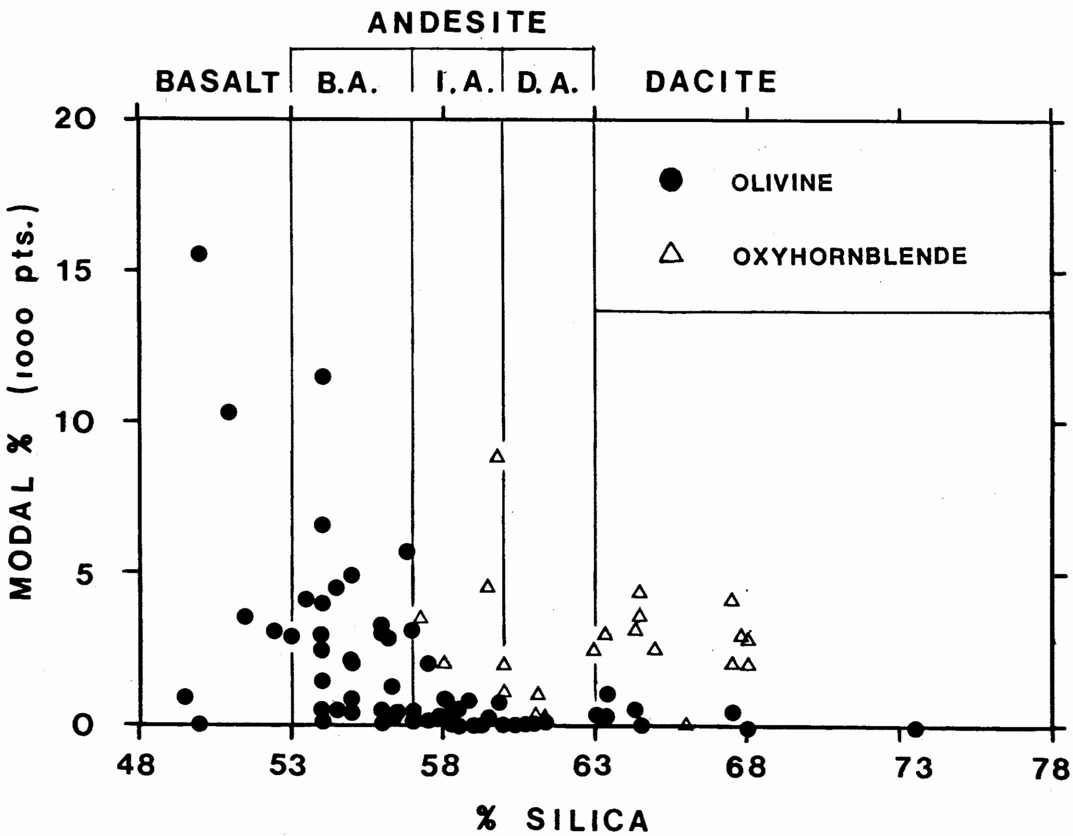


Figure 8. Distribution of modal olivine and oxyhornblende versus silica content for 87 rocks from the Mount Jefferson area. Sources: Greene (1968), McBirney (1968), Sutton (1974) and this study.

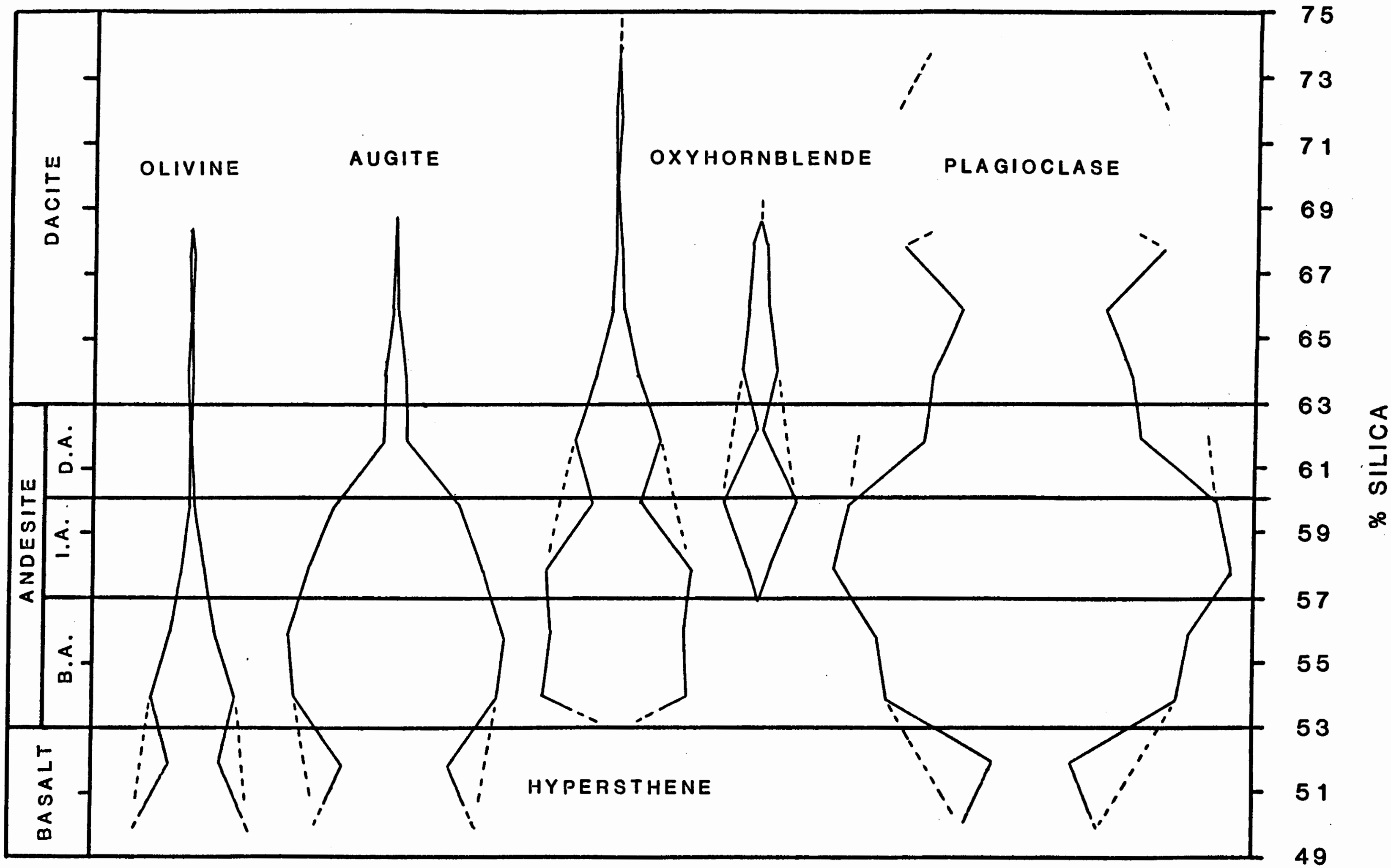


Figure 9. Relative abundance diagram of principal minerals with respect to silica content for 87 rocks from the Mount Jefferson area.

The three main rock classes comprise basalt, andesite and dacite (Table I). Andesite is further divided into three subclasses designated basaltic andesite, intermediate andesite and dacitic andesite. Dacitic andesite replaces the "silicic andesite" class of Greene and Sutton so that all classes are gradationally expressed in compatable rock-name terminology. Basaltic andesite basically follows the recommendations of Williams (Williams, and others, 1954, p. 43, 94). The subclass intermediate andesite incorporates those rocks whose silica values approximate the "average" 58.17 percent of Cenozoic andesite determined by Chayes (1969).

TABLE I. ROCK CLASS CHARACTERISTICS

ROCK TYPE	BASALT	BASALTIC ANDESITE	INTERMEDIATE ANDESITE	DACITIC ANDESITE	DACITE
SILICA CONTENT (%)	~48-53	53-57	57-60	60-63	63-~74
% TOTAL MINERALOGIC COMPOSITION:					
Augite	16-38	0-33	0-23	0-4	0-2
Average	27	16	12	2	1
Primary Mode	?	8.5	3.5	3.0	<2.0
Secondary Mode	?	23.5	16.5	---	---
Hypersthene	---	0-19	0-19	0-15	0-5
Average	---	10	10	7	3
Primary Mode	---	2.5	3.0	4.0	2.5
Secondary Mode	---	13.0	---	---	---
Olivine	0-16	0-12	0-2	tr.	0-1
Average	8	6	1	---	0.5
Primary Mode	?	3.0	2.5	<1.0	<1.0
Secondary Mode	?	---	---	---	---
Oxyhornblende	---	---	0-9	0-3	0-5
Average	---	---	4	2	3
Primary Mode	---	---	2.0	2.5	2.5
Secondary Mode	---	---	---	---	----
Plagioclase	36-53	33-77	21-75	32-60	22-55
Average	45	55	48	42	38
Primary Mode	52?	57.0	37.5	36.0	27.0
Secondary Mode	---	---	64.0	---	50.0?
An (Phenocrysts)	60-80	60-90	61-96	55-67	20-80
An (Microlites)	?	36-50	35-45	?	2-35

LITHOSTRATIGRAPHY

I. INTRODUCTION

Throughout the Quaternary, continual volcanism produced a sequence of lava flows and fragmental material with a minimum combined stratigraphic thickness of 3600 m within the study area (Fig. 10). Also, during the volcanic history, periodic glaciation severely eroded the terrain leaving behind substantial deposits of drift. Subsequent to these events, and persisting into present times, moderately intense colluvial and periglacial processes produced localized surficial deposits of talus, alluvium, colluvium, protalus deposits, rock glaciers and ablation deposits.

Sixteen identified volcanic centers lie within the approximate 46 km^2 of the study area (Fig. 1). Several lava flows or flow sequences are also present which emanated from at least five additional sources outside the immediate area and from local sources no longer identifiable due to erosion or burial by subsequent volcanic units. The stratified products derived from these centers overwhelmingly consist of lava flows, ranging in composition from basaltic andesite to dacite,

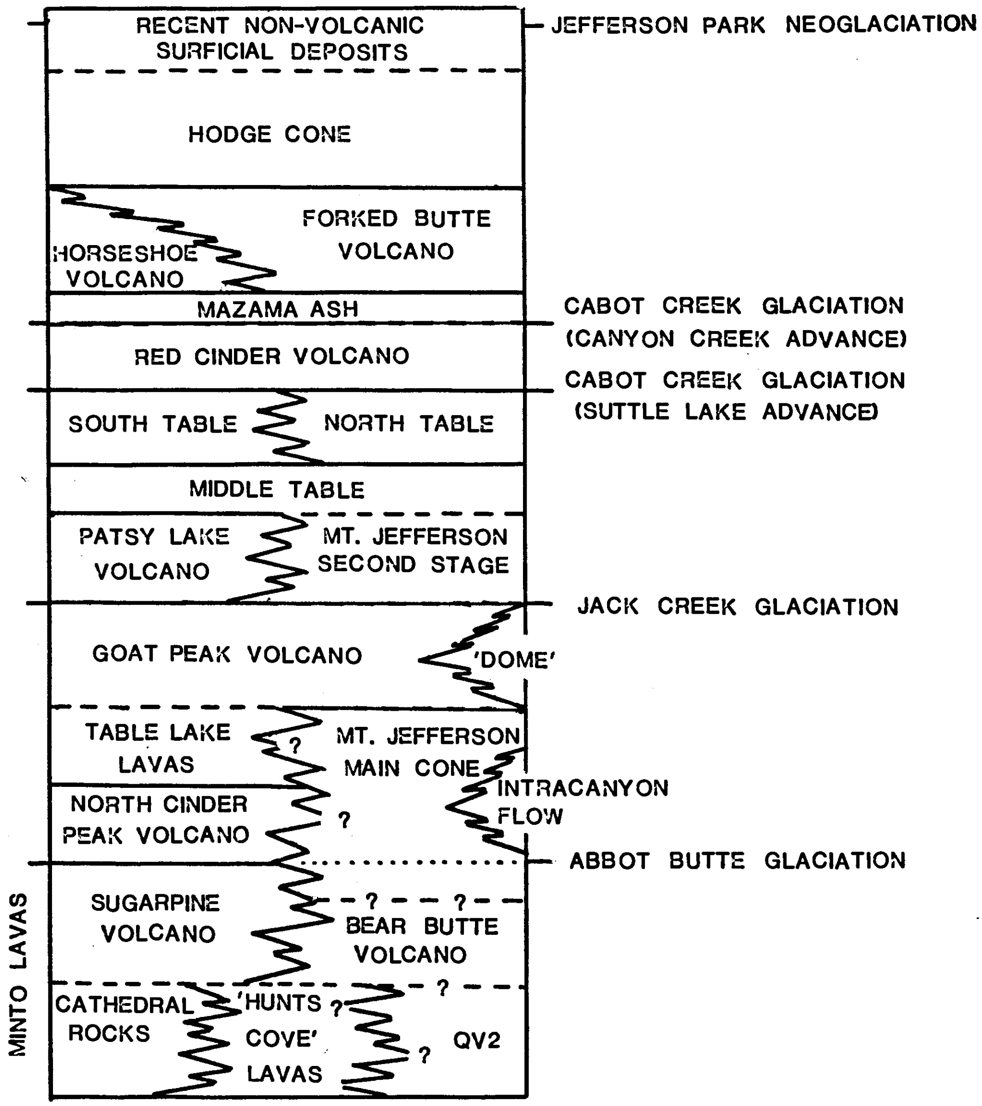


Figure 10. Generalized stratigraphic sequence of the southern flank of Mount Jefferson. Total aggregate thickness of volcanic deposits equal approximately 3600 meters.

although tephra, agglomerates, breccias and rare tuffs are locally important in respective diminishing abundance.

Scott (1977) presented detailed evidence of a three-fold glacial sequence and a period of neoglaciation for the Metolius River area east of the High Cascades crest, including the area covered by this study. His sequence which evidently correlates with that of Thayer (1939) for the North Santiam River area, comprises, oldest to youngest: "Abbott Butte" glaciation; "Jack Creek" glaciation; "Cabot Creek" glaciation ("Suttle Lake" advance and "Canyon Creek" advance with two phases); and "Jefferson Park" advance (two phases) (Fig. 10).

Scott ascribed all the volcanic activity to the interglacial periods, assigning formational names to the resultant volcanic units. These are: "Brush Creek" formation (Abbott Butte/Jack Creek interglacial); "South Cinder Peak" formation (Jack Creek/Cabot Creek interglacial); and the Holocene "Forked Butte" formation (Cabot Creek glaciation/Jefferson Park advance).

Because of the variations in composition and discontinuous nature of the volcanic units, it is important to note that Scott's formational names are time- and not rock-stratigraphically oriented. In the present study, chronological ordering of the volcanic units was determined mainly by stratigraphic relationships with one another (relative depths), relative erosional extent of the volcanic assemblages caused by glaciations, and association with drift deposits identified by Scott (1977) and specific tephra deposits. Volcanic assemblages, however, are still relegated to interglacial periods as, with the possible exception of Mount Jefferson, no evidence is noted for substantial volcanic activity occurring during or transcending glacial regimes.

Nearly all the volcanoes described below lie along or close to the Cascades crest, but a few are situated somewhat off-axis to the east (Fig. 1). The form of these centers is varied, and comprises tephra cones, domes, composite cones and shield volcanoes. The size and complexity of these features is also highly variable. The tephra cones may be small, have single pipe-like conduits and no associated flows, or they may be more composite-like with multiple flows erupted from excentric vents on the flanks. Holocene tephra cones retain much of their original forms. Mount Jefferson, dominating the landscape to the north, is the largest composite volcano near the study area. The more eroded composite and shield volcanoes show internal structures which, again, range from simple, single-vent to complex, multiple-vent forms.

For mapping purposes, the volcanic stratigraphic units composing the volcanic structures are divided into <u>conduit</u>, <u>near-vent</u> and <u>lava flow</u> facies. The first two compose the central facies (in this study) making up the primary form of the volcano, and the third makes up the bulk of the proximal facies or apron deposits (Hammond, 1974, p. 40). Each facies is commonly composed of one or more similar stratigraphic units, most of which merge laterally or vertically with one another, or form discontinuous units. The conduit facies comprise those rocks directly associated with the plugs. They generally include intrusive, hypabyssal, porphyritic rocks with or without large masses of compacted breccia. The near-vent facies consists of generally fragmental materials produced in and ejected from the vent. These include mainly breccias, coarse air-fall deposit (agglomerate) and some subordinate lava flows. The flow facies generally extend radially outward from the vent area for distances commonly up to several kilometers. Interbedded tephra deposits can occur in the proximal areas, but with increasing rarity in the more distal parts. In addition, the character of each volcanic assemblage is further defined by a fairly discrete range of silica content (Fig. 11).

Figure 11. Silica Variation Diagram of Major Volcanic Units Around the South Flank of Mount Jefferson.

EXPLANATION PAGE

Map designation	Stratigraphic Unit(s)
Qv_1	Minto lavas of Hunts Cove
$Qlf_{1,2,3,4}$, Qtf	Lavas of Forked Butte
Qv_2	Volcanic rocks underlying North Cinder Peak
Qnb, Qlb, Qdb	Near-vent rocks, lava flows and dikes of Bear Butte
Qlc, Qdc	Lavas and dikes of Cathedral Rocks
Qth, Qlh	Tephra and lavas of Horseshoe Cone
Qmj	Mount Jefferson Main Cone lavas
Qtc	Tephra of Hodge Cone
Qcn, Qnn, Qln	Plug, near-vent rocks and lavas of North Cinder Peak
Qcs, Qls	Plug and lavas of Sugar Pine Ridge
Qtr, Qlr_1, Qlr_2	Tephra and lava flows of Red Cinder Cone
Qcp, Qlp	Plug and lavas of Patsy Lake volcano
Qtd_1	Middle Table
$Qta_{1,2,3,4}$	Lava flows of the Patsy Lake assemblage
Qtd_3	North Table
Qtd_2	South Table ('x' denotes xenolith)
Qil	Intracanyon flow west of the Tables
Qsj	Mount Jefferson Second Stage lavas
Qdm	Domal feature west of middle Table
Qcg, Qng, $Qlg_{1,2}$	Plug, near-vent rocks and lava flows of Goat Peak

Silica values from: Thayer (1937), Greene (1968), McBirney (1968b), Sutton (1974), Hales (1974), Gannon (1978).

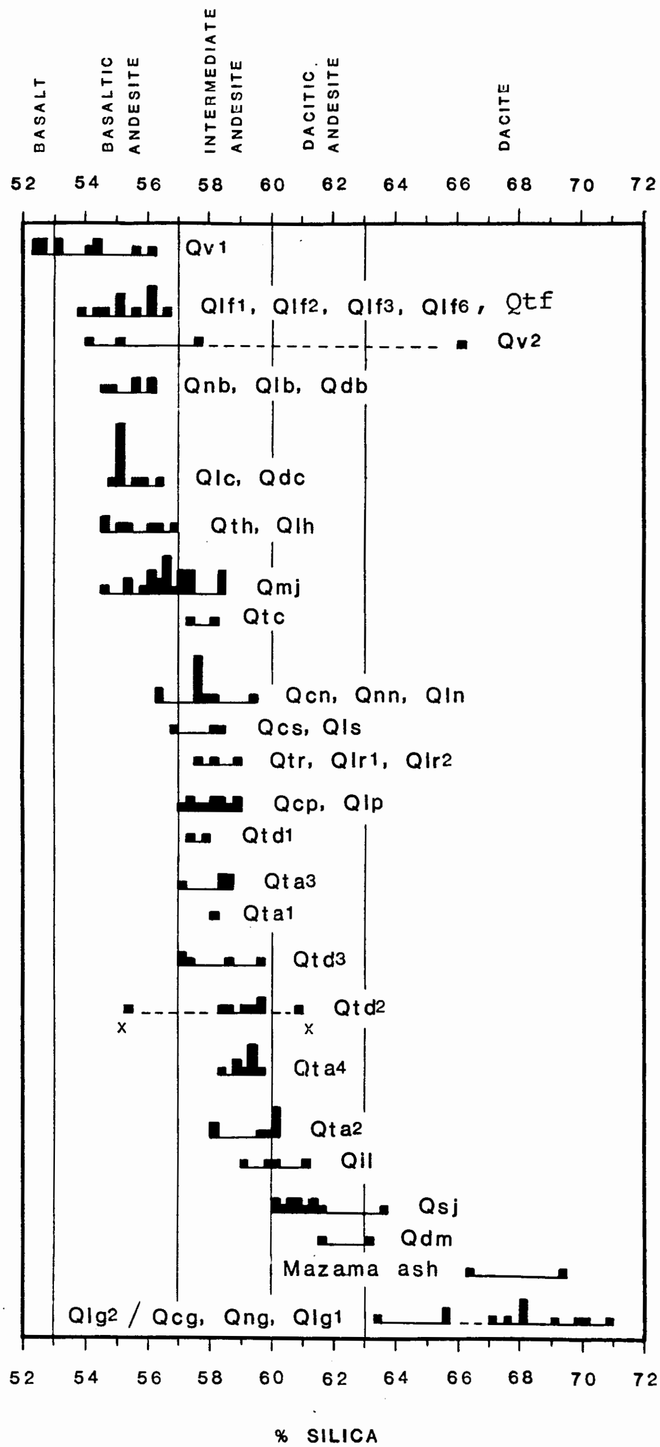


Figure 11 (continued). Silica variation diagram of major volcanic units around the south flank of Mount Jefferson.

II. DESCRIPTION OF VOLCANIC STRATIGRAPHIC UNITS

Minto Lavas

The oldest volcanic rocks (pre-Abbott Butte glaciation) exposed in the study area comprise portions of what Thayer (1937) termed the "Minto Lavas". According to Thayer's map these lavas, whose vents were near the axis of the present High Cascades crest, formed broad coalescing shield volcanoes. As a whole, dips are low, ranging from 6 to 8 degrees near their sources to 1 or 2 degrees in the more distal parts. Dips up to 18 degrees, however, were noted in some of the younger shield volcanoes in the area. The Minto and equivalent lavas compose the primary platform of the younger High Cascades platform upon which more recent composite (strato) volcanoes unconformably rest (Taylor, 1968, p. 3). The Minto lavas are calculated by Sutton (1974, p. 102) to occupy about 1,282 km^3 in the Bend, Oregon Quadrangle (1:250,000).

Within the present map boundaries, the Minto lavas are represented by the older, roughly coeval volcanic rocks of Hunts Cove, Cathedral Rocks, and flows and minor intrusions underlying North Cinder Peak, and the younger, coeval volcanic rocks of Bear Butte and Sugar Pine Ridge (Fig. 1). Each of the respective coeval assemblages appear to interfinger with one another to some extent. For the most part, the rocks of these assemblages are exposed along highly eroded ridges. Rock compositions are predominantly basaltic andesite (Fig. 11).

Volcanic Rocks of Hunts Cove (Qv_1). This largely undivided section of the Minto lavas is restricted to the area around Hunts Cove. The nearest conduits from which at least some of these flows originated are located 1 km west-southwest of Hanks Lake, and on Grizzly Peak Ridge, 2 km northwest of Hanks Lake (Fig. 4). In addition, several dikes up to 4 m wide are exposed on a ridge just south of Hunts Cove (Fig. 1), but there is no evidence that these intrusions grade into flows.

The lava flows and interbedded scoria beds average 8.4 m in thickness, but 1.5 to 3.0 m-thick flows are common (Thayer, 1937; Sutton, 1974). Near Grizzly Peak the flows dip about 10 to 35 degrees quaquaversally southeast and northwest away from the plugs. However, in the cliff face west of Hunts Lake (Fig. 1), dips are to the west and northwest (Sutton, 1974, p. 14) suggesting a source to the east or southeast, perhaps in the Cathedral Rocks area.

In hand specimen, the rocks are light to pale bluish grey, and contain phenocrysts of plagioclase as large as 1 mm and commonly reddish olivine anhedra.

Glomerocrysts of plagioclase form up to 5 mm. The lavas are commonly platy jointed and rarely columnar jointed.

Volcanic Rocks of the Cathedral Rocks (Qcc, Qnc, Qlc, Qdc. The Cathedral Rocks stand as a deeply eroded, castellated ridge at the head of the Hunts Cove cirque (Figs. 5, 12). Specifically, the ridge crest is made up of four prominent pinnacles herein referred to as "south", "south central", "north central" and "north" Cathedral spires. This complex assemblage is composed of lava flows, interbedded scoria, agglomerate, and plugs and dikes of basaltic andesite (Fig. 11) with an aggregate thickness of at least 210 m. Sources of these flows are uncertain, although local lavas may originate from vents along the ridge. Stratigraphic relationships with the lava flows of Hunts Cove are indefinite, but there is a strong likelihood that the two assemblages are roughly coeval and partially interfinger with one another. The rocks of Cathedral Rocks are dense to porous, and vary in color from dark to medium greenish grey. Some are light grey and reddish where oxidized. Phenocrysts of plagioclase, commonly reddish olivine and pyroxene as large as 1.5 mm lie in a typically fine grained groundmass, and form as much as 25 percent of the rock by volume.

South Cathedral spire (Qcc) is a pointed, roughly cylindrical feature interpreted as a plug (Fig. 12). Jointing is widely spaced and has a preferential vertical

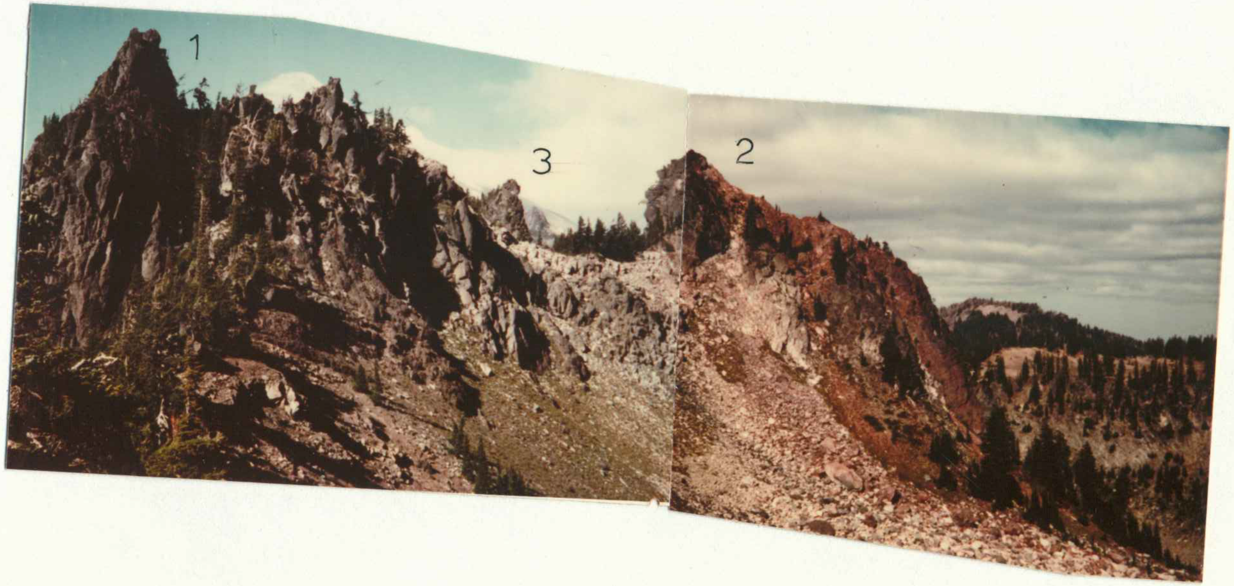


Figure 12. Cathedral Rocks from the south. South Cathedral spire (1) is a small plug, grading into flows to the right. South central Cathedral spire (2) consists mainly of coarsely bedded near-vent agglomerate and flows. North central Cathedral spire (3) is the erosional remnant of a moderately thick lava flow. This highly eroded assemblage formed prior to Abbott Butte glaciation, and probably interfingers with Minto lavas to the west.

orientation. A northwest-trending vertical dike (Qdc), about 3 m wide, abuts the plug at its southwest side. Flows of varying thickness, exhibiting blocky to columnar structure, appear to merge with the plug.

South central Cathedral spire (Qnc) (Fig. 12) consists of coarsely bedded, near-vent flows and agglomerate. Much of the unit is severely oxidized, imparting a brick red color to the rock, and may be part of the cone facies associated with north Cathedral spire.

North central Cathedral spire (Qlc) is an erosional remnant of a 15 to 20 m-thick lava flow of basaltic andesite (Fig. 12) but is relationship to the other units of Cathedral Rocks is presently unknown. The flow has a coarse blocky structure and localized platy jointing.

North Cathedral spire (Figs. 1, 12) is composed mainly of bedded, oxidized agglomerate dipping about 30^{o} north and northeast on the north side of the spire. No associated plug is apparent, but the unit is interpreted as remnant near-vent or cone facies (Qnc) of a small cinder cone, separate from the aforementioned spires of the Cathedral rocks.

Volcanic Rocks Underlying North Cinder Peak (Qv_2). This assemblage, located west of Patsy Lake, unconformably underlies the younger rocks of North Cinder Peak. Here, a roughly 100 m section of interbedded basaltic andesite flows, flow breccias, and agglomerates is exposed, dipping 15 to 17 degrees to the southeast. A northwest-trending vertical dike and southeast-dipping dacite crystal-lithic tuff unit also occur within the assemblage.

The flows (samples 147-156, Fig. 3) are 1 to 3 m thick, range in color from light to dark grey, and exhibit vesicular, diktytaxitic, or dense textures. Some are exclusively fine grained and flow layered, but many have 0.5 to 3.0 mm phenocrysts of plagioclase and reddish or greenish olivine. Most flows, especially the thicker ones, have blocky interiors with basal platy jointed zones that grade upward into flow layered vesicles. The flows also commonly have scoriaceous basal breccias.

Interbedded air-fall deposits comprise reddish colored layers of alternating agglomerate and unconsolidated ash as thick as 11 m. Most of the agglomerate is composed of rounded and subrounded scoriaceous cinders and small bombs rarely larger than 15 cm.

The 5 m-thick crystal-lithic tuff (sample 156) at about 1848 m (6160 ft) elevation, contains plagioclase phenocrysts up to 3 mm and angular lithic clasts of basaltic andesite (?) up to 5 mm in size, set in a pinkish oxidized, fine grained groundmass. These components occur in roughly equal amounts. In outcrop, the rock is massive with some coarse blocky jointing, and in hand specimen, it is compact and shows no layered features. Whole-rock silica determinations classify the rock as dacite (Fig. 11, Appendix). This unit appears to be a remnant of the the partially welded crystalline zone of vapor-phase crystallization of an ash-flow deposit. It has an exposed lateral extent of about 50 m, and dips 15 degrees southeast. It is the only such rock with this texture and composition observed in the study area.

The dike (Fig. 1), about 3 m wide, has an exposed base with horizontally oriented joint columns with polygonal cross sections. The upper portion is blocky jointed. The dike rock varies from light to dark grey, and has textures ranging from porphyritic to aphyric and scoriaceous. In coarser grained interior parts of the dike phenocrysts comprise plagioclase and greenish or reddish olivine. Poikilitic inclusions of olivine and pyroxene occur within the larger plagioclase crystals.

The source of these lava flows and associated rocks is uncertain, but the agglomerates suggest a nearby vent. Although the units could not be traced laterally, contemporaneity with the Cathedral Rocks is suggested by similar stratigraphic positions.

Bear Butte (Qnb, Qlb, Qdb). Bear Butte Ridge trends east-west, and forms the eroded remains of a shield volcano from which flows spread 5 km to the east where they impinged upon the older rocks of the Bald Peter shield volcano (Fig. 4). The northern, western and southern extents are unknown due to erosion and burial by younger flows, but a minimal western extent of 1 km from the summit of Bear Butte is indicated by the mapped limits (Fig. 1).

The main part of the ridge is made up of numerous basaltic andesite flows (Qlb) which have a minimal thickness of 300 m. The lava flows dip generally to the east 8 to 15 degrees, becoming progressively more shallow in the distal regions. The lavas are medium grey, range from 1.0 to 3.6 m thick, and have thin brecciated bases. Flow structure is typically blocky jointed with crude platy jointing at the bases. The rock is generally fine grained, but contains phenocrysts, up to 2.5 mm, of plagioclase, greenish olivine and clinopyroxene.

The main ridge of Bear Butte (Fig. 1) is intruded by several parallel, northwest-trending dikes (Qdb) ranging from 1 to 2 m in thickness, and exhibiting crude columnar structure oriented normal to the contacts. Lithologically, the dikes resemble the adjacent flows, and though they may have served as feeders for some of the Bear Butte lavas, no flows are seen to emanate from them.

In apparent conformity with the model of the evolution of a High Cascade volcano described by Williams (1944), a composite summit cone (Qnb) developed near the shield volcano summit. The remains of this cone form Bear Butte (Figs. 1, 2, 13), and suggests a relatively explosive terminal or later episode for the volcano. Characterizing this cone are many lava flows with alternating, discontinuous beds of fragmental material comprising tuff, lapilli tuff and agglomerate. These flows and fragemental layers are, for the most part, less than 1 m thick. The thickness of the cone is about 120 m.

The fragmental units are colored grey to brown and black, and locally, red, yellow or orange where oxidized through fumarolic activity. Some of the flows have palagonitized margins. Numerous abrupt changes in dip and unconformable overlaps are observed among the layers (Fig. 13). This is due to erosion between successive eruptions and to irregular accumulation around closely spaced vents (Williams, 1944, p. 43).

The summit cone is riddled with numerous basaltic andesite dikes, ranging in thickness from a few centimeters to 2 m, which varied in trend and acted as feeders to the units making up the cone. One prominent north-trending dike, shown in Figure 14 dips 48 degrees to the east. It has a thickness of 1.5 m and displays crude columnar jointing. The dike has weakly developed marginal alteration, and has incorporated xenoliths (Fig. 14). This intrusion appears to pervade the entire cone, and

Figure 13. Bear Butte from the west. The peak is part of the summit composite cone (Qnb) of the Bear Butte shield volcano. Discontinuous, variably dipping flows and fragmental materials are intruded by numerous dikes.

Figure 14. The main dike on the south side of Bear Butte. It strikes due north and dips about 48° east, cutting thin, discontinuous lava flows and breccias. Note the crude columnar structure and scattered xenoliths (marked X). Dikes such as this may have also served as feeders to the older shield volcano lavas.

may well be the parent feeder for it. No central plug was observed for either the shield volcano or the later summit cone, and may have been eroded or buried. However, as Williams (1944, p. 42) suggested for similar volcanoes, much of the earlier formed plug may have been subsequently shattered by eruption of the tuff and breccia.

Sugar Pine Volcano (Qcs, Qns, Qls, Qds). At about the same time as the Bear Butte volcano was formed, another shield volcano developed 2.5 km to the south, presently manifested as Sugar Pine Ridge. Lavas from this volcano (Qls) flowed eastward a distance of 6.8 km. Due to intense erosion, however, its other limits are unknown but, like Bear Butte, the flows were probably less extensive westward where they were impeded by older rocks. Much of the internal structure of the volcano, however, is still preserved.

The lava flows of Sugar Pine volcano are presumably basaltic andesite, although none were analyzed in this study. They form a repetitious series with individual flows ranging from 1 to 3 m in thickness, and dipping 10 degrees eastward. Like Bear Butte, a prominent set of parallel northwest-trending dikes (Qds) intrudes these lavas. They have a generally vertical attitude and range in thickness from 1 to 2 m.

The source of these lavas is located at the northwest end of Sugar Pine Ridge (Fig. 1), where a large part of the central vent is exposed, 1 km^2 in extent. As mapped, the main plug (Qcs) covers 1 km^2, and appears as two planed-off individual masses (Figs. 1; 2, section A-A'). Whether they represent two separate plugs, or a single one, is uncertain. The plug is composed of dense, medium to dark grey andesite and basaltic andesite (Fig. 1) with strongly preferred vertical jointing. Textures are usually fine grained, but the rock has small plagioclase phenocrysts up to 1 mm, and smaller ones of pyroxene.

Sugar Pine volcano also apparently had an explosive late phase in which a series of coalescing tephra cones (Qns) formed on top of the main shield via a network of ascending dikes. Remains of the tephra cones occur peripherally around the plug(s) and, to the east, form spectacular stratified pinnacles of red and grey tuff and lapilli agglomerate with dips of about 22 degrees (Fig. 15). The dikes are considered to be coeval with the ones intruding the shield lavas to the east (Fig. 1). The centralized dikes intrude both the plug rocks and the adjacent tephra deposits, and range in size from stringers a few centimeters wide to dikes 2 m in width. All the dikes have a general northwesterly trend.

Figure 15. Near-vent facies (Qns) of Sugar Pine shield volcano. These bedded tuffs and agglomerates dip steeply away from the plug (off photo to right), and are riddled with dikes.

Total aggregate thickness of Sugar Pine volcanic rocks is about 450 m. The original volcano, including the summit cone, stood at least 200 m higher than its present height.

North Cinder Peak (Qcn, Qnn, Qln, Qdn). After the formation of the earlier volcanoes and their subsequent initial erosion by Abbott Butte glaciation, a volcano complex developed at North Cinder Peak 2.8 km west of the Sugar Pine Ridge vent area (Fig. 1). Later glacial erosion has removed virtually all the northeastern part, and the internal structure is consequently fairly well displayed.

North Cinder Peak developed mainly as a shield volcano, with a minimum aggregate thickness of 450 m, but differs from the others in that the lavas (Qln) are composed of intermediate andesite (Fig. 11). The true extent of the lavas is uncertain, but they flowed northeast at least 1.5 km where they appear to unconformably overlie rocks of the Hunts Cove and Cathedral Rocks assemblages. A section of about twelve of these lava flows is well exposed along the 170 m-high, northeast-facing cliff northwest of the plug (Fig. 16). These medium grey lavas, dipping 14 to 18 degrees northwest, vary in thickness from 2.4 to 6.0 m and show internal structures characteristic of block flows (Fig. 17). Flows of this same general format also are exposed in the northeast-facing cirque southwest of Forked Butte (Fig. 1). In

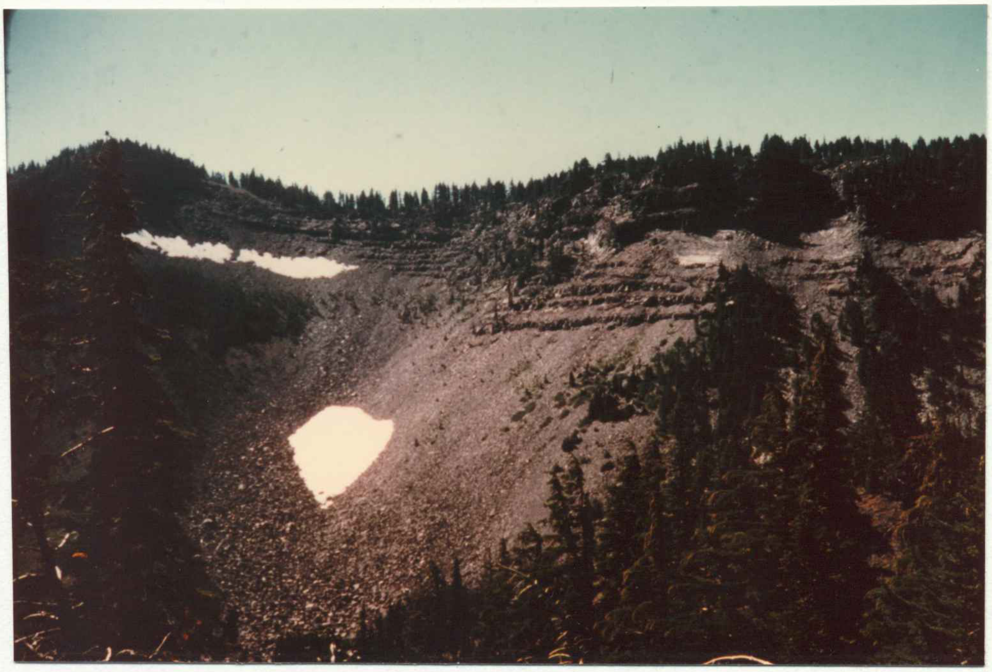


Figure 16. Stratified shield lavas (Qln) of North Cinder Peak exposed in the cliffs south of The Table. The blocky talus below merges with ablation and pro-talus deposits at the bottom of the cliff.

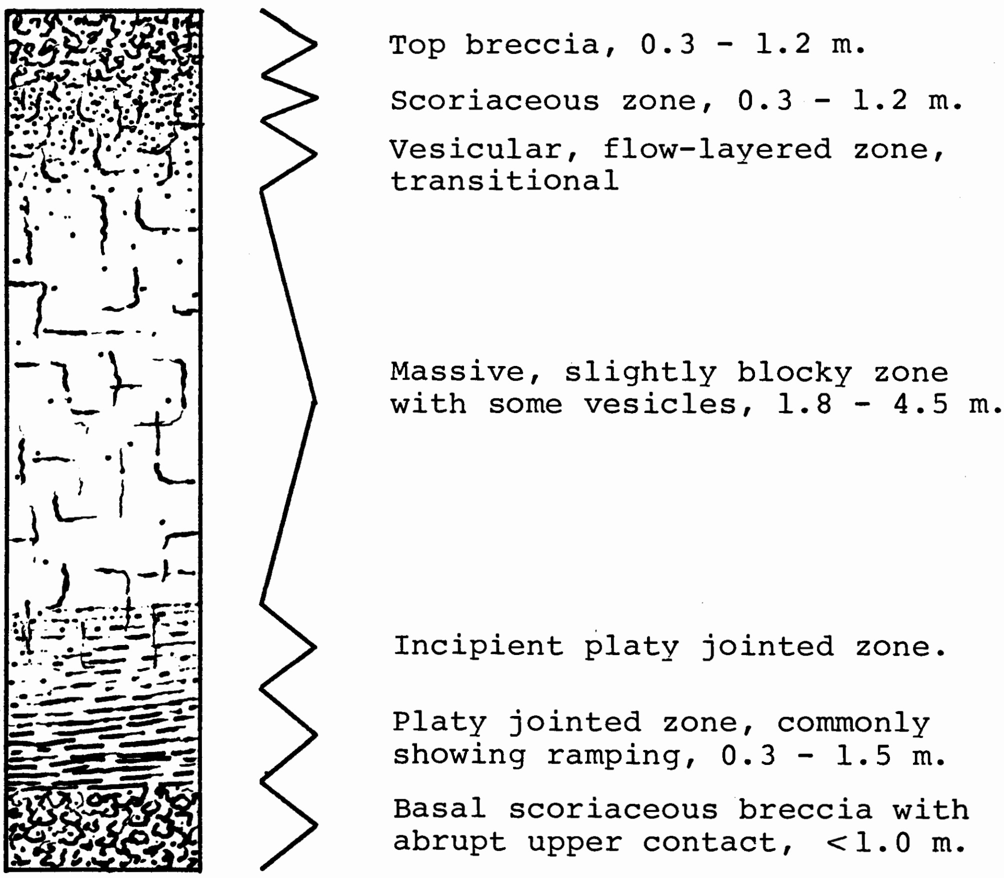


Figure 17. Generalized flow structure of North Cinder Peak shield lavas seen in the cliff face northwest of the plug. Characteristic aa structure makes up these 2.4 to 6.0 m-thick flows.

addition, an intracanyon flow, at least 60 m thick, flowed 6.3 km down the glaciated valley now occupied by Cabot Creek, south of Sugar Pine Ridge (Scott, 1974, p. 50). According to Scott, this flow has good columnar and platy jointing, and resembles rocks exposed on the east side of North Cinder Peak. This flow now forms a prominent bench along the north side of the canyon, and probably unconformably overlies rocks of Sugar Pine volcano. Collectively, the shield lavas are medium grey with phenocrysts of plagioclase and pyroxene less than 1 mm in size, set in a very fine grained groundmass. Some plagioclase glomerocrysts attain 2 mm in size.

The central plug (Qcn) composing the conduit facies covers about 0.04 km^2 and stands 145 m high. It is exposed as a crudely cylindrical mass with preferred platy jointing varying in orientation from horizontal to vertical. Near the top, the jointing acquires a chaotic swirling aspect. Although much of the plug rock is coarser grained than the adjacent lavas, parts of it exhibit the same degree of granularity, especially in the peripheral areas. Zones of scoriaceous lapilli breccia are locally present (Fig. 3, sample 176).

Contiguous with the plug on its southwest side, forming the topographic summit of North Cinder Peak, are the remains of a summit cone (Qnn). Like Bear Butte and Sugar Pine volcanoes, this cone indicates a relatively minor but explosive later or terminating phase. The cone may fill part of the old crater, or simply overlie the earlier flows. It consists of interbedded andesite lava flows, red and black scoriaceous lapilli agglomerates and moderately consolidated ash deposits. The individual flows or the fragmental deposits rarely exceed 1 m in thickness. The deposits forming the cone dip quaquaversally away from the plug (Figs. 1; 2, sections B-B', I-I'). Dips, however, are steeper than underlying lava flows of the shield, ranging from 23 to 41 degrees. This relationship suggests that the summit cone originated mainly from the central vent and not totally from the adjacent dikes (Qdn), which show more of a radial affiliation with the plug. These later lavas generally resemble those of the shield volacano, and, cinders included, all have distinct phenocrysts of plagioclase up to 2 mm in size.

Mount Jefferson

Mount Jefferson (3149 m), the second highest peak in Oregon, dominates the landscape north of the study area. The geology of this large composite volcano, as described by Sutton (1974), consists of two main stages: a "Main Cone" stage (Qmj in this report) of chiefly basaltic andesite; and a "Second Stage" (Qsj) of "silicic" (dacitic) andesite lava flows. Lavas of both stages associated with the southern flank of Mount Jefferson occupy much of the northern quarter of the mapped area (Fig. 1).

Main Cone Eruptive Units (Qmj). The first stage, comprising basaltic andesite lavas (Fig. 11) and fragmental materials, form the main bulk of the volcano. The early phase of this stage is represented by a tephra cone formed about 1 km west of the present summit (Sutton, 1974). The second phase consists of successive lava flows from at least two vents, unconformably overlying the earlier cone. Fragmental deposits in these later flows is negligible.

The lava flows collectively developed to an original cumulative thickness of at least 600 m, with dips ranging from 20 to 45 degrees. Individually, the flows vary from 1.5 to 12.0 m thick, with average thicknesses of 3.0 to 4.5 m. They are generally dense (blocky?) with no columnar structure, and many have underlying reddish orange scoriaceous flow breccias. Flow layering is rare. In hand specimen, the rocks are medium to light grey with phenocrysts of plagioclase and pyroxene set in a fine grained groundmass.

Second Stage Eruptive Units (Qsj, Qaj). According to Sutton (1974), the second major stage of Mount Jefferson's development included local flows of silicic andesite (Qsj) (dacitic andesite in the present terminology; Fig. 11). Remnants of these lavas cap some of the ridges of

Mount Jefferson, and individually attain thicknesses up to 45 m. The summit of Mount Jefferson is formed by a 30 m-thick portion of one such flow. The main eruptive center for these lavas was probably close to the present summit as suggested by a zone of highly altered rock in that vicinity (Sutton, 1974).

Additional dacitic andesite flows and associated agglomerates (Qaj) erupted from two fissures on the south flank of Mount Jefferson, near the west side of Waldo Glacier. One arm of a thick blocky flow moved southward where it was bifurcated by the slightly older Goat Peak volcano (Fig. 1). The western lobe continued to flow in a southwest direction, somewhat beyond the limits shown by Sutton (1974). The eastern lobe's limits remain uncertain, having been covered by later volcanic units. The western arm roughly parallels the western lobe of the other, where they both terminate within 1 km northeast of Shale Lake.

In hand specimen, these rocks appear light to medium grey, and contain phenocrysts and glomerocrysts (up to 5 mm) of plagioclase and hypersthene. The groundmass portion is characteristically fine grained and dense.

Intracanyon Flow North of Cathedral Rocks (Qil)

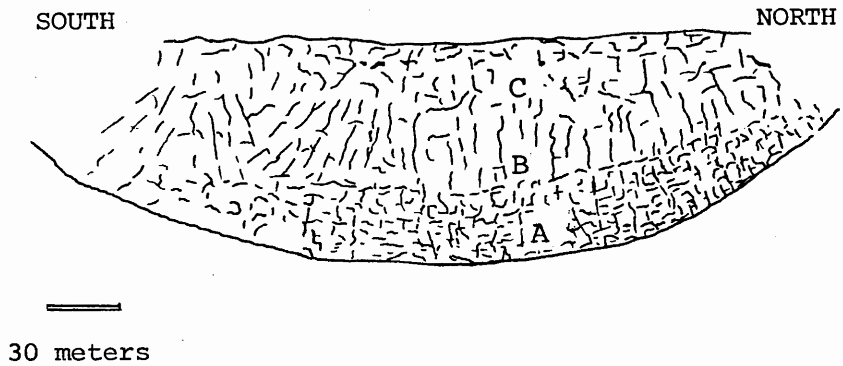
A beheaded 115 m-thick intracanyon flow, reminiscent of Llao Rock at Crater Lake, is exposed in cross section just north of the Cathedral Rocks, and west of the middle

Table (Figs. 5, 18, 19). This dacitic andesite flow occupies an old glacial valley, and unconformably overlies rocks of the Minto group, and possibly Main Cone lavas of Mount Jefferson. The flow slopes northwest about 7 degrees (Fig. 2, sections G-G', H-H'), and extends for at least 1 km in that general direction. Its vent area is not evident, having been eroded by subsequent glacial advances or buried by later volcanic deposits. However, a source area to the southeast is indicated, by projection, possibly underlying the south Table (Fig. 1). The presence of this flow suggests, too, a former topographic high in the area (cirque) presently occupied by The Table.

The internal structure of this flow is well-displayed in its truncated west face, and is schematized in Figure 19. Simply, the flow consists of a roughly 30 m-thick coarsely platy jointed basal zone, with superposed pseudo-columns which grade abruptly upwards into a 30 to 40 m-thick crudely columnar jointed zone. This, in turn, grades transitionally into a 20 to 30 m-thick blocky jointed upper zone. The columns tend to develop perpendicular to the adjacent valley walls.

The rock is light to medium grey, and has a speckled appearance due to phenocrysts of plagioclase, pyroxene and hornblende up to 2 mm in size. Some glomerocrysts occur

Figure 18. Intracanyon flow (Qil) adjacent to older lavas of the Cathedral Rocks (left). Mount Jefferson lavas outcrop at the upper right. The flow is about 115 m-thick. View is from the northeast.



A. Dense, crude primary platy jointing with superposed, irregular and incipient columnar jointing. The columns tend to form normal to the valley sides. The upper part of this zone is more hackly jointed.

B. Coarse columnar jointing with some fanning. The zone contacts zone A sharply, and is transitional with zone C above.

C. Coarse, irregular, blocky jointing.

Figure 19. Generalized cross section of the beheaded intracanyon flow (Qil) north of Cathedral Rocks.

as large as 3 mm. The groundmass is typically fine grained and dense.

Goat Peak Volcano

This assemblage comprises at least four successively thick, lithologically similar lava flows of intermediate andesite, informally named the "Table Lake" lavas (Qta_{1-4}), and two overlying hornblende dacite lava flows ($Qlg_{1,2}$). These lava flows with a minimum aggregate thickness of 230 m, form the ridge east of the middle Table and the upland between Bear Butte and Table Lake (Fig. 1). Although the headward parts of these lavas are covered by younger tephra, the source is presumed to be at or near the site of Goat Peak, located excentrically on the flank of Mount Jefferson in the northwest part of the study area.
The Table Lake lavas vary somewhat in mineralogy and silica content but are sufficiently discrete in contrast to the dacite flows to suggest two eruptive episodes (Fig. 11).

Table Lake Lava Flows (Qta_{1-4}). Four thick lava flows of intermediate andesite (Fig. 11) were erupted in the cirque presently occupied by The Table, then progressively southeast and east along the glaciated south side of Bear Butte (Fig. 1). The eastern extent is unknown due to later burial by the "Horseshoe" tephra cone (Qth) and its lavas (Qlh). The flows are numbered 1 to 4, in order of approximate decreasing age. The southern margin of the sequence has been truncated to some degree by glaciation, and some of the earlier flow(s) may underlie younger pyroxene andesite lavas of Patsy Lake (Qcp, Qlp), described below.

Dips vary from near 10 degrees in the headward parts, or more where the lavas flowed over irregular ground. In some places near-horizontal attitudes are attained. On the basis of general southeasterly and easterly dips and trend of the flows, their stratigraphic position with respect to adjacent units, and the overlying dacite flows which appear consanguinous with Goat Peak, Goat Peak is inferred to be the source for these lavas.

The structure of the flows is fairly simple. Each consists of a usually well-defined basal platy jointed zone grading into a blocky jointed zone above. Each major flow comprises several coalescing flow units which are manifested as arcuate lobes forming a compound lava flow. These lobes are readily apparent on aerial photographs and, to some extent, on topographic maps. The development of lobes is best displayed in flow Qta_2 (Fig. 1). Along flow margins the basal platy zone parallels the termination of the lobe, and commonly ramps steeply upwards, almost vertically in some places. Successive lobes flow beyond these margins in a presumably laminar fashion. In some places, these compound blocky lava flows attain a thickness of over 100 m, and individual flow units range from at least 10 to 45 m. The lobar feature situated south of Hole-in-the-Wall Park, shown as Qta_2 (Fig. 1), was mapped by Greene (1968) as an intrusion, but it is interpreted here as a flow unit. This topographically and petrographically anomolous feature, however, may be a plug or a partially buried, non-related intracanyon flow.

These lavas are light to medium grey, and generally have a speckled appearance due to plagioclase, pyroxene, olivine and oxyhornblende phenocrysts scattered throughout a fine grained groundmass. The phenocrysts are rarely larger than 2 mm except for sparse glomerocrysts and some oxyhornblende crystals which grow to 4 mm.

Flow Qta_4 is anomolous with respect to the other flows in that it is typically aphanitic, with small phenocrysts making up only about 1 percent of the rock. Flow structure is characteristically platy jointed and flow layered, and the rock commonly has a mottled appearance due to streaky aggregates of microlithic plagioclase in the groundmass. This flow has apparently been eroded in its upper parts, resulting in a patchy outcrop pattern (Fig. 1). At its eastern (exposed) extremity, it cascaded over the earlier flows, and presently forms the northern edge of Jefferson Lake.

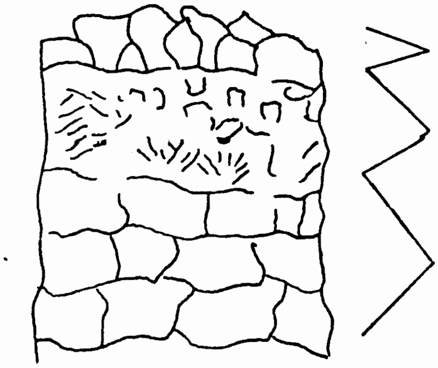
Goat Peak Hornblende Dacite Lava Flows (Qlg_1, Qlg_2). The ridge crest east of the Tables is made up of remnants of two successive, blocky hornblende dacite lava flows which overlie the Table Lake lavas (Figs. 1; 2, sections D-D', G-G'). The bulk of this sequence consists of the earlier flow (Qlg_1), whereas the younger flow (Qlg_2) remains only as two isolated patches capping the ridge crest (Fig. 1).

The trend of the flows bears about south 25 degrees east, and dips range from 25 degrees to horizontal, depending on the underlying topography. Much of the western part has been eroded during the final formation of the adjacent cirque, and the headward portions are buried by later tephra deposits from "Red Cinder" cone (Fig. 1). Considering the trend of these flows and their petrographic consanguinity with Goat Peak, they almost certainly originate from that locale. The maximum discerned extend of these lavas is therefore about 2 km.

Flow Qlg_1 is characterized by blocky and localized "cordwood" columnar jointing. The columns typically form 15 to 20 cm-wide polygons in cross section and are commonly oriented at or near right angles to the slope and probable cooling front. The high degree of perfection in some of these small columns suggests that they are part of the flow interior where a steady state of cooling was maintained.

Flow layering, manifested as 1 to 3 cm-wide, colored zones, is evident in many places and tends to form normal to the long axis of the small columns. Phenocrysts of oxyhornblende, as large as 5 mm, stand out in contrast to the otherwise whitish grey color of the rock, and are crudely flow-aligned. Less obvious phenocrysts of plagioclase, up to 2 mm, are abundant. Most of the upper portion of the flow is oxidized to a reddish pink color, probably as a result of escaping volatiles.

Flow Qlg_2 differs from flow Qlg_1 in that it is slightly less silicic (Fig. 11), and has a dark to blackish grey color and glassy appearance. Although outcrops are limited, the headward parts are sufficiently exposed to suggest that this flow comprises several flow units which collectively dip up to 48 degrees to the southeast. Jointing is typically blocky or cordwood-like, and platy jointing appears to be more common than in Qlg_1 (Fig. 20). These rocks have plagioclase and up to 15 percent oxyhornblende phenocrysts set in a normally blackish grey, glassy and fine grained groundmass. Oxyhornblende phenocrysts are commonly flow aligned. In places the rock weathers to a reddish lavender color. Flow layering (foliation) is characteristically well-developed, and has the same relationships noted in Qlg_1. The southern outcrop (Fig. 1) consists mainly of very well developed cordwood columns.



C. $\geq$3.0 m.

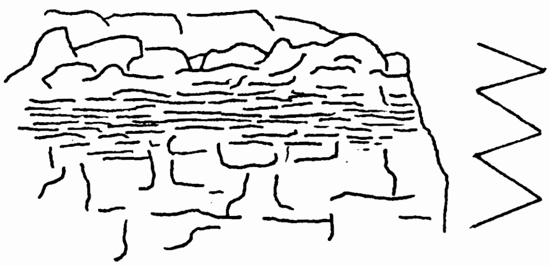
B. 6.0 - 7.5 m.

A. $\geq$12.0 m.

A. Irregular, non-oriented blocks 0.6 to 1.2 m in diameter.

B. 'Cordwood' and some columnar jointing (ca. 10%). Cordwood columns 5.0 to 50.0 cm wide. Some small fan joints not strictly normal to flow surface. Some structural contortion. Rock sample No. 72 taken from lower part of unit.

C. Massive blocky jointing.



C. $\geq$3.0 m.

B. 1.5 m.

A. $>$1.5 m.

A. Blackish grey, glassy, fine grained. Some compositional layering with reddish rock. Bedding in sets or parting with scoriaceous material. Contact with platy jointed zone above gradational within 10 cm. No break in bedding although rock has flow banding generally parallel to the bedding. Oxyhornblende present to 15% by volume.

B. Medium grey, platy jointing zone with aphanitic groundmass. Plates 0.5 to 5.0 cm-thick. Plate attitudes vary from N33° -42°E (strike) and 48° to 55° S.E. (dip). Oxyhornblende and plagioclase phenocrysts predominate.

C. Well developed blocky jointed zone with a crude platy jointed transitional zone below (ca. 1.5 m). Flow banding occurs commonly in lower parts. Oxyhornblende present at 10 to 15% by volume. Rock sample No. 71 taken from platy jointed transitional zone.

<u>Figure 20.</u> Two generalized sections of the younger Goat Peak hornblende dacite flow (Qlg_2) located at the north end of the ridge immediately east of the north Table.

Goat Peak (Qcg, Qng). Goat Peak (2148 m) stands as a prominent pyramidal mass of hornblende dacite. It is composed of a conduit facies, a plug (Qcg), and a fragmental near-vent facies (Qng). The plug has an irregular blocky jointed structure, and is whitish grey to reddish brown in color. Plagioclase and conspicuous oxyhornblende phenocrysts are abundant, with glomerocrysts of the latter attaining lengths of 6 mm. No flow layering was noted. A lobe of Mount Jefferson Second Stage dacitic andesite lava appears to be diverted around Goat Peak (Fig. 1), although the contacts between units are covered by younger deposits.

The contiguous near-vent facies (Qng) on the south side of Goat Peak is made up of crudely stratified thin lava flows (less than 30 cm thick) and fragmental material. Much of the latter comprises flow breccias, but there appears to be an abundance of large angular blocks incorporated in the flows as well, and some of the units are consolidated lapilli breccias. In this unit's southern extremity, northwest of the north Table, dips of 22 degrees to the north (towards Goat Peak) were noted. This outcrop, however, may be a large slump block, and the attitude indicated may be misleading.

"Dome" Southwest of Goat Peak (Qdm)

A 48 m-high, conical promontory is situated between Goat Peak and the intracanyon flow, Qil. This feature is oval in plan, and measures about 120 m in its long direction. Its northeastern half has been truncated by glacial erosion.

The rock is generally dense with coarse blocky jointing, its color ranges from medium to blackish grey and is locally reddish. Thin flow layers (laminae), having a blackish or pinkish color, pervade the porphyritic hornblende dacite and dacitic andesite (Fig. 11) making up this feature. Conspicuously large phenocrysts of oxyhornblende occur up to 2.5 cm in length. They exist separately, as aggregates or as glomerocrysts, and make up to 4 per cent of the rock by volume. Plagioclase phenocrysts also are large, attaining sizes of 5 mm, and compose as much as 25 percent of the rock. The groundmass portion is fine grained.

The well developed flow layering occurs in much the same manner as in the Goat Peak dacite flows. These generally steeply-dipping laminae range in width from a few millimeters to several centimeters, and appear to be roughly concentric with the outline of the feature (Fig. 1). Several incorporated xenoliths were noted and appear less silicic than the surrounding host rock.

In view of these characteristics, the feature is best interpreted as a small endogenous dome, and the flow (foliation) planes suggest an internal structure similar to that achieved experimentally by Reyer in 1888 (Williams, 1932, p. 87, 144).

Patsy Lake Volcano (Qcp, Qlp)

This largely undivided sequence of intermediate andesite flows (Qlp) originates from a denuded plug (Qcp) located immediately south of the south Table. The plug and the headward portion of some of the adjacent flows have been partially covered by Holocene tephra of "Hodge" Cone (Figs. 1, 5).

Due to extensive vegetation and till cover, the number of flows is uncertain, but two dozen is probably a realistic estimation. In addition, many flows probably consist of several flow units. The outline of lobes and pressure ridges, not readily distinguishable on the ground, are visible on aerial photographs. These lavas flowed eastward at least 3.5 km, and have a minimum extent of 3 km^2. They form the southern margins of both Table Lake and Jefferson Lake, where contacts and internal structures are exposed. Good exposures also occur near the plug and where they butt against the thick Table Lake lavas to the north (Fig. 1).

The uppermost lavas in the sequence are the best delineated, and average 3 to 4 m thick. Typical structure consists of a platy jointed base grading into a blocky-jointed zone above. Both basal and top breccias are present, and are on the order of 25 cm thick. The upper portions of most flows are vesicular, and vesicles are commonly flow-aligned. Phenocrysts of plagioclase average 2 mm in size, with glomerocrysts up to 4 mm. Together, these make up normally about 10 percent of the rock volume. Smaller phenocrysts of pyroxene and rare olivine collectively make up about 3 per cent. The groundmass is fine grained. Rock colors are mainly medium to dark grey, but some are reddish or pinkish due to oxidation of the groundmass constituents.

Flows lower in the sequence are somewhat different in that they are generally finer grained and lighter colored. Sparse olivine phenocrysts, averaging about 2 per cent of the rock by volume, are more abundant than pyroxene. Flow structures are similar to the younger lavas, but thicknesses tend to be greater, ranging from 3 to 6 m. These flows are best exposed along the southern margins of the assemblage.

The plug (Qcp) has an extent of about 0.1 km^2 and stands 72 m high. The north and east sides are partially covered by Holocene tephra (Qtc) (Fig. 5) and the base is mantled by talus and protalus deposits. The plug is elongated in a northwest direction, probably due to glacial erosion.

Overall, the plug rock is blackish grey, porphyritic, and has an irregular fine blocky or brickbat joint structure. In many places, however, a larger structural fabric is seen consisting of steeply inclined or vertical pseudo-columns. These are actually sets of ascending intrusive flows or "dike sets" about 30 cm wide which appear to grade into the lavas. Each one is separated from the others by thinly brecciated interfaces. There is a secondary cordwood-type joint structure normal to the flow plane of these features. Possibly, the entire plug is composed of a network of these dike sets.

The plug rock is mineralogically and texturally similar to the lava flows, but pyroxene phenocrysts are more abundant, making up about 10 percent of the rock. The dark color is due largely to a high glass and opaque content in the groundmass. Rocks of the Patsy Lake assemblage are also texturally similar, and have comparable silica contents to those associated with The Table (Fig. 11).

The Table Domes (Qtd_{1-3})

Three imposing flat-topped eruptive features occupy the large cirque between Goat Peak and Patsy Lake (Figs. 1, 5). They were collectively named "The Mesa" by Hodge (1925), and on later maps they are referred to as "The Table". Despite their somewhat unusual morphology, they have received little detailed attention in the literature.

These features are designated in this study as "south Table" (Qtd_2), "middle Table" (Qtd_1) and "north Table" (Qtd_3). The Tables are interpreted here as a set of three coalescing incipient domes, or domes transitional with stiff (blocky) lava flows. They each possess most or all of the following attributes:

1. alignment along a probable fissure;
2. flat topped;
3. generally oval to circular in plan, with abrupt, steep sides;
4. limited lateral flowage;
5. surficial arcuate lineations in concentric patterns;
6. localized divergent fanning of flows seen in cross section;
7. localized, steeply dipping flow layering (foliation) around the margins;
8. oxidized surface rocks.

The Tables are contiguously aligned, north-south, along the High Cascades axis and, together, cover about 2 km^2. They all appear oblong in plan and, although glacially scoured by Suttle Lake glaciation, they still retain much of their original forms. The middle Table (Qtd_1) is the older of the three, and probably had an original near-circular configuration. Its true shape, however, is obscured by the younger, nearly coeval south and north Tables which partially overrode it (Figs. 1,2, section B-B'). The visible portion of the middle Table covers about 0.7 km^2, and has a relief of 135 m. The south Table (Qtd_2) has an areal extent of nearly 1 km^2, and an average relief of 150 m. On its north side it thickens and overlaps the south side of the middle Table to a height of 60 m. The north Table (Qtd_3) is 60 m high and has an area of 0.5 km^2. It covers the middle Table to a height of about 15 m. All the Tables are composed primarily of porphyritic hornblende intermediate andesite (Fig. 11), and are among the coarsest grained rocks in the study area. Individual oxyhornblende phenocrysts attain lengths of 1 cm.

Concentric arcuate lineations are seen on the surfaces of the Tables, and are manifested as alternating broken ridges of oxidized lava and shallow troughs (probably breccia zones) filled with ground moraine (Figs. 5, 21). Due, probably, to its relatively unimpeded development, the lineations are most well-developed on the middle Table. The lineations, however, have a more confused aspect on the south Table (Figs. 1, 5). These arcuate features are probably a surficial manifestation of individual flow units ramping upwards.

Figure 21. Glaciated upper surface of the south Table showing a scabby appearance due to ground moraine of the Suttle Lake advance surrounding exposures of oxidized flow rock. These exposures outcrop concentrically, and represent steeply dipping flow planes. Canyon Creek till borders the south Table on the right, forming a distinct moraine. North Cinder Peak is in the left center background, and Forked Butte is in background to the left.

Along the northwest face of the south Table a pronounced fan structure is displayed (Fig. 22). Thin (25 to 50 cm-thick) feeder flows, resembling the so-called dike sets in the plug of Patsy Lake volcano, rise vertically and radiate from the probable vent area. Away from this presumed vent area, the flow units acquire a nearly horizontal attitude, coalesce, and incorporate blocks of earlier cooled (crustal?) lava (Fig. 22). In their terminal and lateral parts, the flow units appear to ramp upward as their viscosity increased in a manner characteristic of block lava flows (Macdonald, 1972, p. 94; Hammond, 1974; p. 43). This ramping is exhibited in a gully on the eastern side of the south Table where a 14.3 m-thick flow unit consisting of a 7.5 m-thick blocky interior, a 5 m-thick basal platy jointed zone and a 1.8 m-thick, greyish brown to reddish, scoriaceous top breccia, dip inward as much as 75 degrees (Fig. 1.). The ramping is best displayed in the platy jointed zone.

All the rock exposed on the top surfaces of the Tables is reddish-pink in color, has a punky, porous nature, and tends to be friable. Except for minor, sporadically distributed zeolite(?) minerals in the vesicles, little secondary mineralization was noted on a macroscopic level.

Figure 22. Exposed cross section of the west side of the south Table. Note divergent fanning of the flow units at left, probably close to the vent, and large lava blocks rafted along flow planes to the right. Height of cliff is about 75 meters.

Flow layering, expressed as colored laminae ranging from a few millimeters to a few centimeters thick, is displayed in places along the outer margins of the Tables. These laminae are developed by alternating layers of glassy and crystalline rock, and reflect flow directions of the lava. Most of these laminae have steep or near-vertical dips (Fig. 1). The flow layering is best seen in areas of freshly exposed or relatively unweathered rock, and is best exemplified on the south Table (Fig. 23). On the northwestern corner of the south Table, the flow layering attitudes, like the arcuate lineations, are more contorted, and appear to reflect the impeding effect of the middle Table upon the expansion of the younger south Table (Fig. 1).

The complex cooling history of the Tables is indicated by three main types of jointing in the rock: blocky; hackly-cordwood; and platy. Coarse blocky jointing is restricted to the upper portions of the Tables (Figs. 23, 24), but with irregular distribution. More orderly fine blocky, hackly (brickbat) and cordwood jointed rock tends to dominate the intermediate regions. In these locales, such as the southeast side of the south Table, the long axes of the more columnar blocks are commonly oriented normal to the slope (Fig. 25). In the finer blocky or cordwood jointed rock, the plane of

Figure 23. Steeply dipping flow banding in blocky jointed andesite on the south side of the south Table.

Figure 24. Internal flow structure exposed on the east-central side of the north Table. The platy jointed zone underlying the upper blocky jointed zone formed probably in response to downslope movement of the lava. The section shows characteristics common to typical blocky aa lava flows.

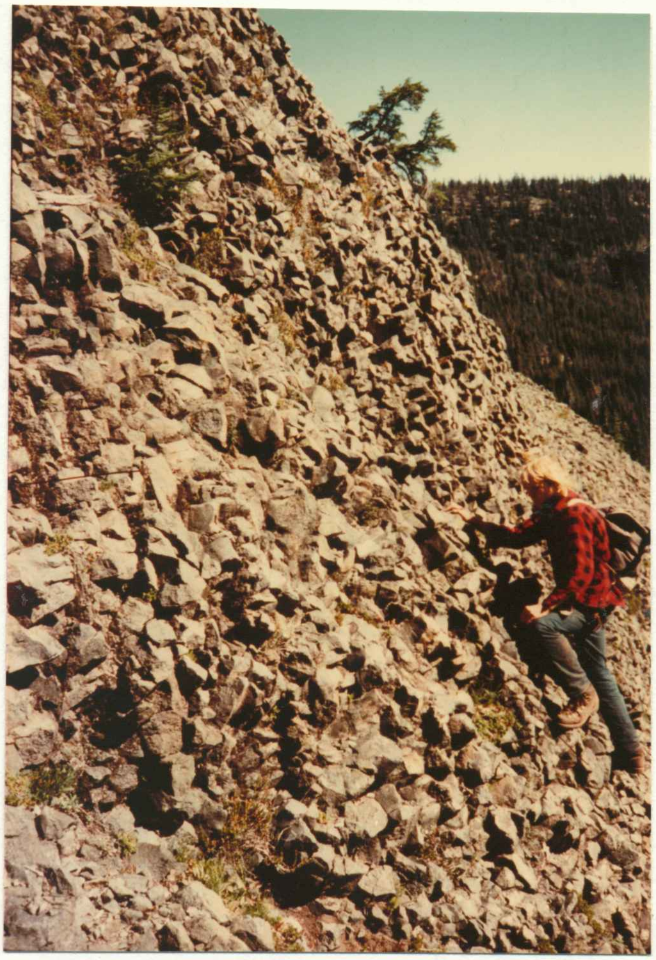


Figure 25. Cordwood-blocky jointing in andesite on the southeast side of the south Table. Orientation of the crude columns is roughly normal to the slope, and may reflect a former cooling front.

flow layering varies from normal to parallel to the long axes of the joint columns. In the latter case, peripheral fracturing of the rock tends to occur in the foliation plane. Platy jointed rock is mainly associated with the basal portions of the blocky jointed flow units (Fig. 24).

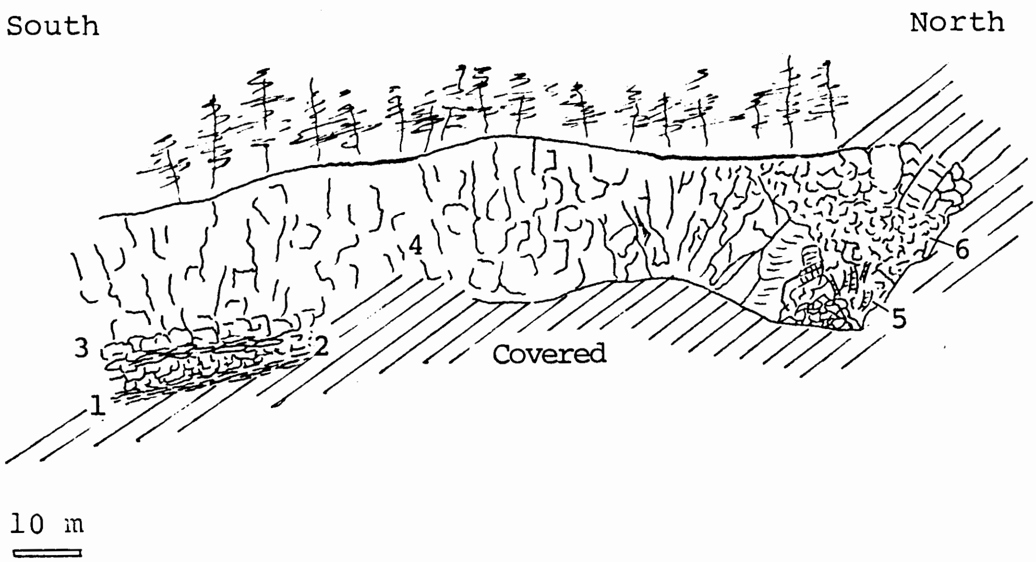
Xenoliths are commonly incorporated in the flow rocks of the Tables (Fig. 26). These vary considerably in size, are rounded to subrounded, and appear markedly different from the host rock both texturally and mineralogically. The margins show little or no effects of thermal alteration (baking, crazing, etc.). Most of the xenoliths, however, have thin rinds measuring 0.5 to 0.6 mm which may be due to normal weathering. This same rind thickness is within the mean established by Scott (1974, p. 30; Fig. 7) for cobbles of Jack Creek till. The rinds, shapes of the xenoliths, and their textural and compositional variability suggest they are till components caught up in the ascending lavas of the Tables.

The relatively small size of the north Table facilitiates investigation of the general internal structure of the Tables. The vent of the north Table, however, evidently formed on a slope (Fig. 2, section B-B'), allowing the lava to flow down a steeper gradient than that underlying the south and middle Tables.

Figure 26. Rounded xenolith of scoriaceous rock incorporated into the southeast side of the south Table. Note the lack of crazing or marginal alteration.

The interior of the north Table is well exposed on its east side (Figs. 24, 27). A section observed in the east-central part shows platy jointed rocks in unit 3 (Fig. 27) dipping 20 to 30 degrees to the south and southeast. The blocky jointed rocks above (upper part of unit 3 and unit 4) show flow layering with attitudes of the same general magnitude, although somewhat more variable (Fig. 1). These attitudes probably reflect the general flow direction of at least this portion, but they may also be influenced by the proximity of the older Goat Peak dacite flows to the east.

At the northeast corner, where the headward portion of the north Table is covered with Holocene tephra (Qtbr) and colluvium, the flow structure acquires a different, more chaotic character. Here, the rock (units 5 and 6, Fig. 27) is finely blocky jointed with localized, superposed pseudocolumns, commonly having secondary joints normal to the long axes. These columns average 10 to 75 cm in length, and, again, resemble the 'dike sets' observed in the Patsy Lake plug (Qcp). Intercalated with this zone are irregular shaped pods and stringers of reddish to reddish grey, scoriaceous rock with contacts varying from abrupt to gradational. The oxidized rock suggests volatile activity, and along with the chaotic flow structure, indicates proximity to the vent.



1. Coarse to moderately fine platy jointing associated in some places with a basal oxidized scoriaceous (breccia) zone. ⩾0.5 m.

2. Medium size, moderately compact blocky jointing. 2 - 3 m.

3. Fine blocky jointing, grading downward into crude, tabular and wedge-like platy jointing. Unit dips about 20° south. 1 - 4 m.

4. Coarse, massive blocky jointing with localized large incipient columns displaying fan structure in some places. 15 - 20 m.

5. Densely packed, fine blocky and brick-bat jointing with numerous small, variously oriented 'dike sets'.

6. Dense, fine blocky and brick-bat jointing with localized incorporated and peripheral zones of oxidation and scoria pods.

Figure 27. Generalized drawing of the east side of the north Table showing internal structure.

Immediately downslope (south), the rock acquires a more massive, blocky jointed character with superposed large, incipient columns (Fig. 24, unit 4). Locally (near units 5 and 6), these pseudocolumns have a fan-like configuration, diverging upwards (Fig. 27), suggesting a turbidity situation in response to lava flowage over an irregular ground surface. The contacts between the compact, massive, blocky jointed unit 4 and the upper part of unit 3 below (fine blocky jointed rock) commonly show signs of oxidation.

At the southeast corner of the north Table, the flow structure takes on yet a different character. Here, a thick mass of cordwood-hackly jointed rock is exposed similar to that seen on the southeast face of the south Table (Figs. 25, 28). Flow layering is evident within this unit, dipping about 55 degrees north in apparent response to north Table lavas impinging onto the middle Table (Figs. 1; 2, section B-B'; 28). Further to the south, where these lavas evidently prograded the middle Table, the flow layering becomes less steep (about 30 degrees).

The cordwood jointed unit is 'overlain' by a roughly 50 cm-thick zone of reddish and blackish, scoriaceous and somewhat rubbly breccia zone (Fig. 28), probably continuous or transitional with the basal part of unit 1 (Figs. 24, 27). This breccia is, in turn, locally overlain by massive, blocky jointed rock possibly equivalent with

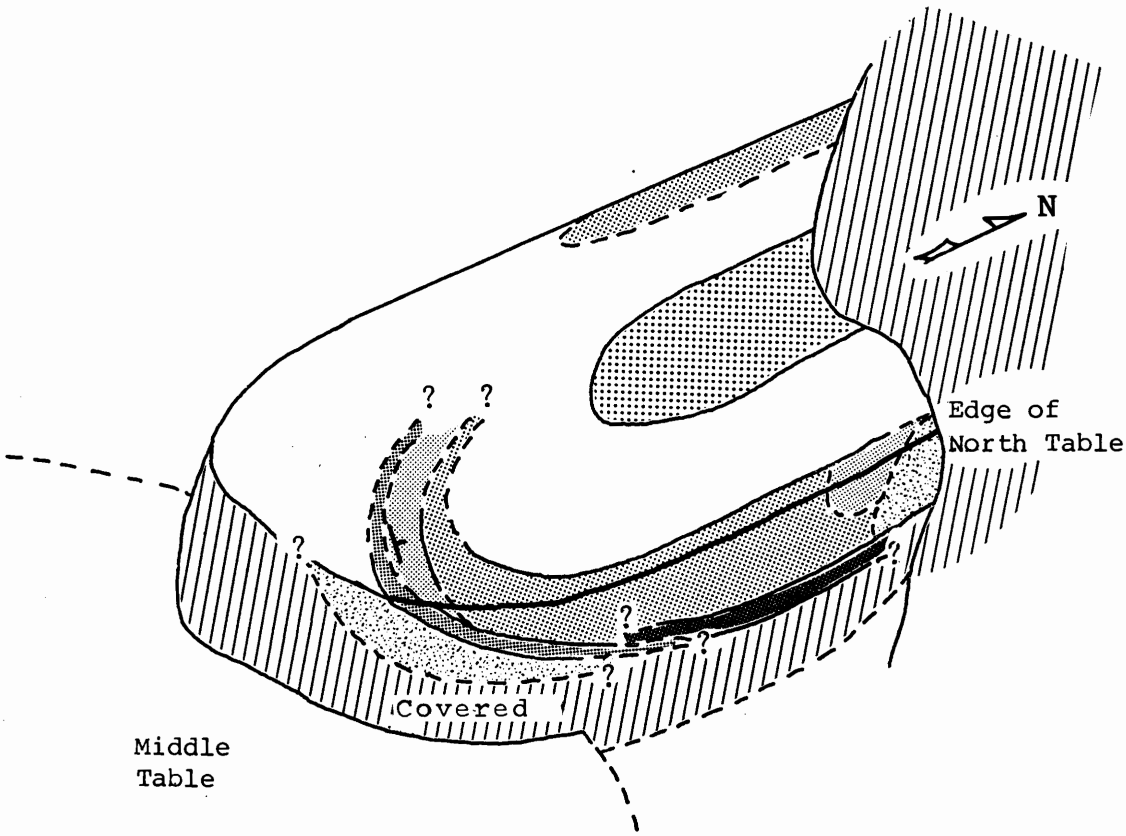


Figure 28. Simplified oblique view of the inferred structure of the north Table, looking northwest. Layering is shown as: compact cordwood and brickbat jointing; scoriaceous and oxidized 'breccia'; transition zone of oxidized flow rock; coarse blocky and crude columnar jointing, oxidized in upper part; fine blocky and platy jointing; Canyon Creek till. The layers ramp upward in probable response to downslope flowage being obstructed by the middle Table.

unit 4 (Figs. 24, 27). Between the blocky jointed rock and the scoria zone is a gradational zone of oxidized flow rock which may correlate with units 2 and 3 (Figs. 27, 28). The breccia zone ramps steeply upwards as much as 83 degrees near the southeast corner, and crops out on the surface in an arcuate manner (Figs. 1, 28), forming a slight topographic low relative to the more resistant adjacent rocks. On top the north Table, near the western limit of its outcrop, the breccia zone has locally incorporated into it some crudely ellipsoidal nodules ranging from 30 to 60 cm in diameter. Their interiors are compact and the outer parts are more scoriaceous and vesicular, and permeated by radial fractures. Their configurations suggest that they are pillow lavas.

Red Cinder Cone (Qtr, Qlr_1, Qlr_2, Qtbr)

Red Cinder Cone, named by Hodge (1925), is situated 1 km northeast of Goat Peak, well up on the south flank of Mount Jefferson with which it has either an excentric or adventive relationship (Fig. 1). It stands at 2126 m (7086 ft), has an average relief of 180 m, and covers about 0.5 km^2 (Fig. 29).

The cone (Qtr) is mantled by red and black scoriaceous lapilli, bombs and ash, and has been breached on its southwestern side during the emission of two lava

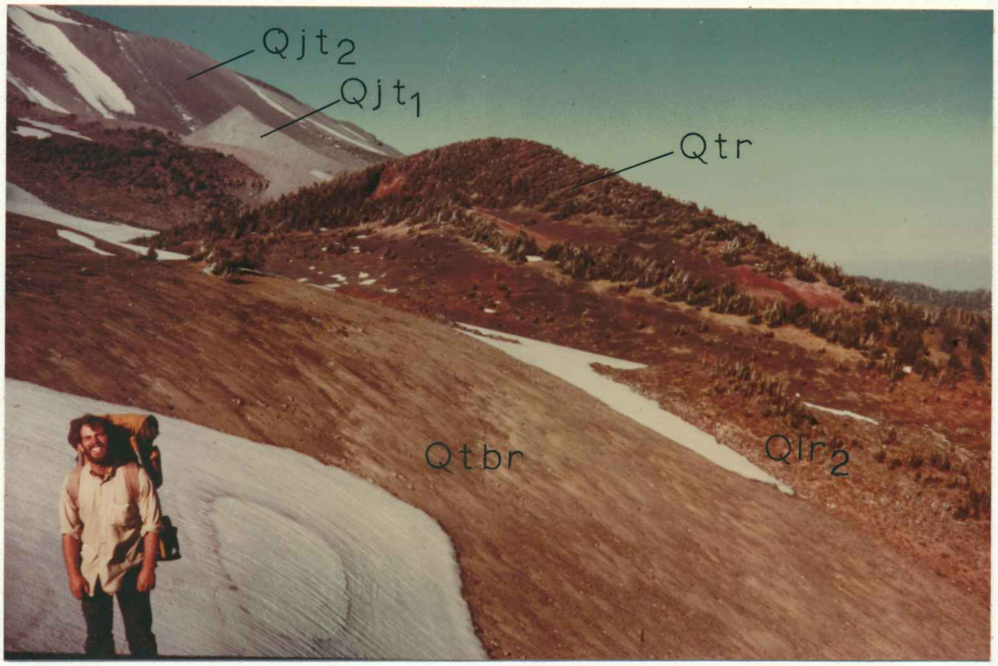


Figure 29. Red Cinder Cone (Qtr) with reworked tephra blanket (Qtbr) in foreground admixed with till. Mount Jefferson rises in the background mantled with fresh looking moraines of the Jefferson Park advance (Qjt_1, Qjt_2). The west and southwest sides of Red Cinder Cone have undergone minor erosion during the Canyon Creek advance of Cabot Creek glaciation.

flows. The older flow (Qlr_1) moved south and southeast and cascaded into Hole-in-the-Wall Park (Fig. 1). Its headward parts were subsequently covered by an air-fall blanket (Qtbr) which probably accompanied the major phase of cone construction. This blanket deposit covers much of the area along the eastern flank of Goat Peak as well as the headward portions of the Goat Peak dacite flows and the north Table. It, like both the cone and the flows, has apparently been mildly affected locally by glacial activity during the Canyon Creek advance of Cabot Creek glaciation (Scott, 1974). Consequently, much of the tephra blanket is reworked and admixed with till.

The younger flow (Qlr_2) proceeded along the same course as the earlier flow, and continued east, along the north side of Bear Butte Ridge, a distance of at least 5 km. The headward part of flow Qlr_2 has a thickness of up to 60 m, thinning to 3 m or less in its distal parts. Both flows display characteristic aa features, and have a blackish grey color in the unweathered interiors. Much of the flow surfaces, however, are scoriaceous and oxidized.

The rocks of both flows have conspicuous phenocrysts of plagioclase and small pyroxene crystals. Flow Qlr_1 is distinguished by the presence of small olivine phenocrysts. Compositionally, the flows are intermediate andesite.

Horseshoe Cone (Qth, Qlh)

Horseshoe Cone, informally named by Scott (1974), lies on the south slope of Bear Butte Ridge (Fig. 1). It has a relief of about 165 m, covers nearly 0.6 km^2, and is breached on its southeastern side.

The cone (Qth) appears uniformly dark grey in its upper parts, reflecting the color of the scoriaceous tephra of which it is composed. Adjacent tephra blanket deposits (unmapped), however, are colored in shades of orange, grey and brown, and resemble the blanket deposits of Forked Butte (Qtfb).

The lavas (Qlh) emanate from beneath the cone, overlie the terminus of the Patsy Lake lavas and dam Jefferson Lake. In addition, they cover a portion of the Table Lake lavas. The lavas spread eastward down Jefferson Lake valley beyond the limits of the map. Their extent is uncertain due to the overlying or interfingering relationships with the presumably younger Forked Butte lavas.

The flows are mainly basaltic andesite, and show surficial aa characteristics. The rock has a fresh looking, medium to dark color except in proximity to the vent where it acquires a reddish hue due to oxidation. Textures range from compact to scoriaceous. Conspicuous 1 to 2 mm plagioclase phenocrysts occur along with smaller (ca. 0.5 mm) phenocrysts of olivine and subordinate pyroxene.

Mazama Ash

A distinctive yellowish orange air-fall ash (not shown in Figure 1) is found discontinuously in the study area, and probably originates from the climactic Mount Mazama eruption 6640 B.P. (Rubin and Alexander, 1960, p. 161). This ash occurs up to 40 cm thick in meadows and along lake margins, but thicknesses of 15 cm are more common. The latter is compatible with the calculated ideal fall-out thickness expected for the Mount Jefferson area, derived from the curve of Williams and Goles, 1968, Fig. 2). Individual grain size rarely exceeds 0.5 mm.

This pumiceous ash, as also noted by Scott (1974, p. 54) and by Mullineaux (1974, p. 27-28) for similar ash in the Mount Rainier area, appears white to light grey where it has been deposited in lakes or bogs. The more common pale orange, yellowish orange and brown colors are due to weathering.

Forked Butte (Qtf, Qdf, Qlf_{1-6}, Qtfr, Qtfb)

Forked Butte lies between North Cinder Peak and Sugar Pine Ridge (Figs. 1, 21). Certain aspects of the cone and its associated flows have been described earlier by Walker, and others (1966), Greene (1968), McBirney (1968), Scott (1974) and Sutton (1974). It was originally designated as "Twin Volcano" and "Twin Cinder Peak" by Hodge (1925).

Although Forked Butte covers about 0.8 km^2, its apparent height is misleading due to its formation along a northwest-trending fissure (Qdf) which transects a 240 m-high cirque wall (Fig. 2, section C-C'). The trace of the fissure is readily visible on aerial photographs. Two remnant craters occur at the summit, and the south side has been breached by lavas emanating from a 15 m-wide boca in the area adjacent to the craters.

Most of the cone is mantled with tan pumice, reddish and black scoriaceous lapilli and ash (Qtf). The tan colored pumice is restricted to the east side, and the black scoria covers most of the south and west sides. Reddish tephra occurs locally, mainly in the craters and on the north slope. In the craters, the tephra has depths of at least 45 m, and occurs mainly as agglomerate. Very little of the ejecta clasts exceed 13 cm in size except near the vents where they range up to 25 cm.

A well-stratified, peripheral tephra deposit from Forked Butte (Qtfb) blankets much of the immediate area around the cone. This sequence of orange, brownish and blackish lapilli and ash occurs up to 2.5 m thick in places, and directly overlies the yellowish Mazama ash. A test pit, "T-4" (Fig. 3), excavated near the north base of the cone, revealed a stratigraphic section of this deposit (Fig. 30, Table II). Two eruptive phases are

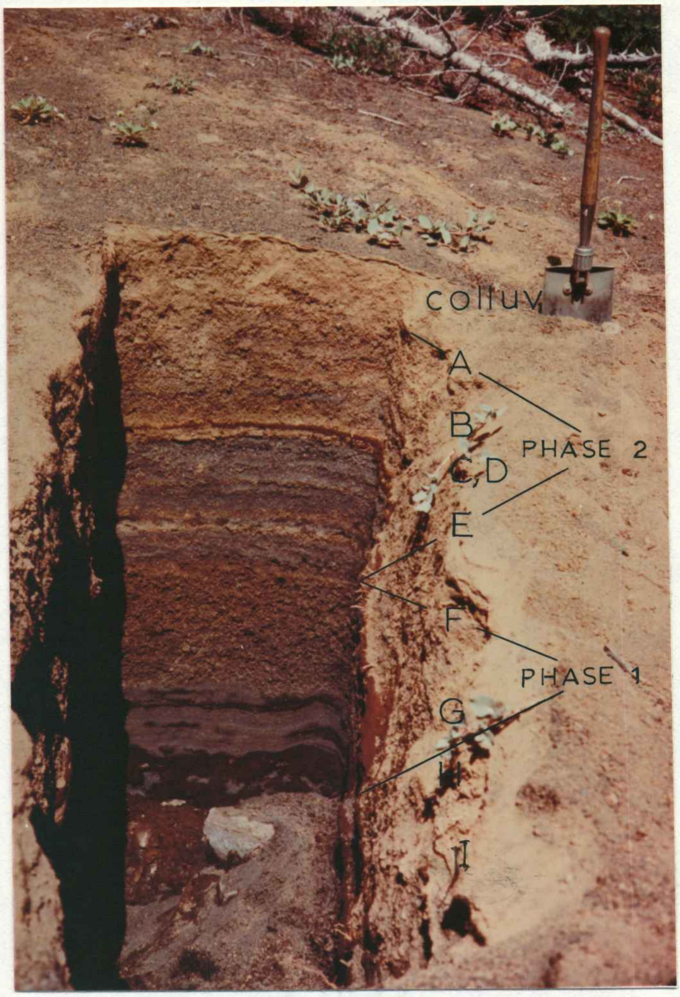


Figure 30. Forked Butte tephra blanket deposit (Qtfb) seen in Pit No. T-4 near the north base of Forked Butte. Fine ash to moderately coarse lapilli make up this sequence (Table II) which suggests two eruptive phases. Unit I is probably tephra from Mount Mazama.

TABLE II. STRATIGRAPHIC SECTION OF FORKED BUTTE TEPHRA, PIT No. T-4

	UNIT	THICKNESS (cm)	COLOR	SIZE RANGE	SORTING AND COMPACTION	TEXTURE AND COMPOSITION
	Colluvium	15	orange	⩽ 3 cm	poor sorting, loose.	mixed ash, pebbles and thin sod.
PHASE 2	A	27	mixed orange and grey	⩽ 2 cm	poor sorting, loose.	crudely stratified, oxidized, scoriaceous lapilli and very fine ash.
PHASE 2	[slightly gradational contact]					
PHASE 2	B	7	orange, brownish orange	⩽ 2 mm	fair sorting, moderately firm.	mildly intrastratified ash and dust.
PHASE 2	[sharp contact]					
PHASE 2	C	16	blackish grey, rare orange	1 cm to 1/4 cm	moderately poor sorting, moderately loose.	weakly intrastratified scoriaceous lapilli and sandy ash.
PHASE 2	D		blackish grey, rare orange	1 mm to 1 cm	moderately poor sorting, moderately loose.	weakly intrastratified scoriaceous lapilli and coarse ash.
PHASE 2	E	11	faint orange, blackish grey	1/16 mm to 1/2 cm	moderately poor sorting, moderately firm.	weakly intrastratified fine lapilli and very fine ash.
	[mildly sharp contact]					
PHASE 1	F	28	greyish orange	1/16 mm to 3 cm	poor sorting, loose.	coarse, oxidized, scoriaceous lapilli and very fine ash.
PHASE 1	[sharp contact]					
PHASE 1	G	10	blackish brown, rare orange	⩽ 1 mm	moderately good sorting, moderately firm.	moderately coarse ash, good intrastratification.
PHASE 1	H	12	orange brown	⩽ 1/2 cm	good sorting, moderately firm.	coarse to fine ash, massive, clayey, mottled.
	[sharp contact]					
	I (Mazama Ash)	10+	yellowish orange to tan	⩽ 1 mm	moderately good sorting, moderately friable.	moderately coarse to very fine ash, somewhat clayey; has foreign pebbles incorporated; probably reworked.
		1.36 m Total				

suggested by a repetition in the sequence, divided by the contact between units E and F.

This blanket deposit is revealed as a 20 cm-thick unit of coarse grained black ash in Cabot Lake, 3 km southeast of Forked Butte (Scott, 1974, p. 54). It is separated from a 15 cm-thick unit of white Mazama ash by 9 cm of lake sediment. Through study of the sedimentation rates, in Cabot Lake, Scott determined that Forked Butte erupted 6400 to 6500 B.P.

Lavas of basaltic andesite erupted along the main fissure as aa flows which retain a very fresh appearance. At least six major flows are recognized, and are numbered according to approximate decreasing age, from 1 to 6 (Fig. 1). Flows Qlf_{1-2} formed concurrently with the main pyroclastic phase or phases of the cone, as indicated by their proximal parts being covered with tephra. These flows are also the most voluminous.

The first flow (Qlf_1) evidently erupted near the headward part of the fissure, and cascaded north down the cirque wall where it exhibits 2 m-thick flow units with clinkery surfaces, blocky interiors, and rubbly basal breccias. The western margin of the flow's headward extremity is covered with later cone material. Flow Qlf_1 initially travelled down Jefferson Lake valley, past the mouth of Cabot Creek, a distance of at least 15 km. This particular flow has been attributed to Horseshoe Cone by

Walker, and others (1966, plate 1), Scott (1974, p. 55), Sutton (1974, p. 29) and Hales (1974, p. 48), but there is some indication that this flow originated from Forked Butte. For example, Horseshoe Cone lavas appear to be overlain by Forked Butte lavas (Qlf_1) in the vicinity of Horseshoe Cone (Fig. 1). Here, hummocky (aa) Horseshoe Cone lavas appear to have temporarily ponded south of the cone. Forked Butte lavas, displaying a more graded surface, appear to flow past this locale. The lava flows known to emanate from Horseshoe Cone seem, on the whole, to be slightly more vegetated as well. Additional suggestive evidence for this interpretation is given in the section dealing with the petrography. In any event, Forked Butte and Horseshoe Cone may be considered nearly contemporaneous eruptions.

The lava contributing to flow Qlf_1 was eventually diverted around the south side of Sugar Pine Ridge. This flow (Qlf_2) cascaded into Cabot Creek Canyon (outside mapped area) which it followed to the mouth. Here, further progress was apparently obstructed by flow Qlf_1. Flow Qlf_2 also breached a substantial part of Forked Butte's south side. Parts of the cone (Qtfr) were transported to the southwest where the lavas temporarily ponded before flowing northward, down the slope above Patsy Lake (Fig. 1). Flow Qlf_3 erupted apparently on the west side of Forked Butte, and flowed northward where it terminated at the

Figure 31. Fresh looking aa lava flows (Qlf_5 and Qlf_6) emanating from the north flank of Forked Butte. These flows are approximately 6400 years old, and butt up against Patsy Lake lavas (Qlp) to the left.

base of the cone's northwest side. Flow Qlf_4 consists of a centralized leveed stream which followed the Cabot Creek flow (Qlf_2), south and southeast, where it cascaded over older intracanyon flow(s) of North Cinder Peak, 1.5 km southeast of Forked Butte. The youngest lava flows ($Qlf_{5, 6}$) with very fresh appearing aa surfaces (Fig. 31), erupted from a vent low on the north side of the cone, and abruptly terminated against older Forked Butte and Patsy Lake lava flows.

Hodge Cone (Qtc)

"Hodge Cone" is the name given here to the small tephra cone contiguous with the south Table on the latter's south side (Fig. 5). The cone has an oval outline, in an east-west direction, and rises about 84 m above its surroundings. A well-preserved crater exists at the summit which measures roughly 100 m wide and 30 m deep. It is usually occupied by an ice-fed lake.

Hodge Cone is made up primarily of tan colored, scoriaceous lapilli and ash (Qtc). Small angular blocks and irregular bombs, up to 30 cm, occur near the rim in mild concentrations. These larger fragments are dark grey, intermediate andesite. It buries a portion of the Patsy Lake plug and impinges on part of the south side of the south Table. The cone has not produced any lava flows. Flow rock of Patsy Lake volcano is exposed in the crater's southeast side (Figs. 1; 2, sections B-B', D-D').

This small volcano represents the most recent volcanic activity in the area as it appears to overlie the blanket deposits of Forked Butte. It may also reflect the last activity associated with the presumed fissure system along which the Tables erupted. Although its age presently remains unknown, the relatively good preservation of Hodge Cone suggests it is no more than a few thousand years old.

III. NON-VOLCANIC SURFICIAL DEPOSITS

Glacial/Ice-Contact Deposits

Surficial deposits that have formed as a direct consequence of glacial ice or permanent snow consist of till, outwash, protalus deposits and ablation deposits. Some of the glacial drift makes up the oldest non-volcanic surficial material in the area.

Till and Outwash Deposits. Although the study area was subjected to Abbott Butte glaciation, no associated drift deposits have been recognized locally. The nearest related Abbott Butte drift lies well to the east and the southeast, in the vicinity of Abbott Butte (Fig. 4).

The oldest recognized glacial deposits in the study area consist of localized deposits of till attributed to Jack Creek glaciation. Remnants of this till are restricted to those areas which were isolated from the impact of subsequent glaciations. Locally, most, if not all, the Jack Creek till (not shown in Fig. 1) is confined to the upper surface of Sugar Pine Ridge (Scott, 1974, Fig. 15, Plate 1), as a thin veneer of mainly subangular to subrounded cobbles in a purplish grey, sandy matrix. Weathering rinds on the cobbles have a mean thickness of 0.4 to 0.6 mm (Scott, 1974, p. 29, 30; Fig. 7).

Deposits produced by the final (third) major glacial event, the Cabot Creek glaciation (Suttle Lake advance), comprise till, as ground moraine, which is exposed (not shown in Fig. 1) throughout most of the study area not covered by subsequent volcanic or glacial units. The surfaces of the Tables were scoured by this advance, striating the bedrock and leaving behind a veneer of till up to 1 m thick (Figs. 1, 21) which has been admixed with younger till and various tephra blanket deposits.

The second advance of Cabot Creek glaciation, the Canyon Creek advance, was limited to cirques, valley heads and the larger peaks (Scott, 1974, p. 40, 41). The till units (Qct) are manifested in the area as a terminal moraine just northeast of Red Cinder Cone, and, tentatively, as a series of small lateral or medial moraines (Qct) on and around the Tables (Figs. 1, 21).

Neoglacial drift, formed during the Jefferson Park advance, is restricted to the slopes of Mount Jefferson. These comprise outwash deposits (Qjo) and till as fresh looking terminal and ground moraines (Qjt), and are shown in Figures 1 and 29 in the vicinity of Red Cinder Cone. The outwash deposits have impinged upon the earlier Canyon Creek moraine in that area. The neoglacial deposits stratigraphically overlie Mazama ash (Scott, 1974, p. 81).

Protalus and Ablation Deposits. Protalus deposits (Qp) are common in the area, and although some are still active, most were formed during the two phases of the Canyon Creek advance. They form by rock debris sliding down and accumulating at the bases of permanent or ephemeral snow fields, and appear as sinuous, moraine-like, block deposits at the base and parallel to steep slopes. Several occur in the Cathedral Rocks locale. Others occur near North Cinder Peak, Goat Peak, and more locally, Patsy Lake plug, the south Table, and above Hole-in-the-Wall Park (Fig. 1). Their sizes are variable, but generally appear larger and more well developed with increasing elevation.

Ablation deposits (Qa) are basically flat-lying, but highly irregular fields of poorly sorted, blocky, rock debris deposited originally on ice- or snow-covered surfaces. With the melting of the ice (ablation), the rock veneer becomes lowered and acquires a typically jumbled and hummocky character. Some of the blocks are as large as 6 m. Small kettle-like lakes are common in these features which suggest the presence of localized residual ice cores. The two main accumulations of this material occur to the west of the middle Table and west of Patsy Lake plug (Fig. 1). They tend to interfinger with other features such as protalus and talus deposits.

Other Deposits

Virtually all the slopes in the study area are covered with Holocene unconsolidated rock debris of various kinds. They comprise fragmented bedrock and reworked older surficial materials such as till and tephra, and are formed primarily by freeze-thaw, water run-off and gravity processes. Specifically, these are mapped as alluvium (QHa) and talus, including colluvium (QHt), and landslide deposits (QHl). Small rock glaciers also occur close to the study area.

The two main areas of alluvium occur in Hole-in-the-Wall Park and "Bear Meadows" which lies immediately south of Bear Butte. Talus deposits are present on all slopes to some degree, in both stablized and unstabilized states. Sizes of indivual blocks range from small cobbles to huge blocks several meters in diameter. Some of the largest accumulations lie along Cathedral Rocks, Sugar Pine Ridge and North Cinder Peak (Fig. 16). At the north base of North Cinder Peak and the east base of Cathedral Rocks, the talus interfingers with ablation deposits.

A lobate mass, mapped by Scott (1974, Plate 1) as Canyon Creek till, lies just south of Hodge Cone (Fig. 1), and is interpreted here as a debris slide (QHl). The deposit originated from the steep cliffs of exposed North Cinder Peak lavas, leaving behind a distinct headward scar. A small lake lies at the toe through the lobe's abuttment with the south side of the Patsy Lake plug (Qcp).

Surficial deposition, by and large, is still continuing at a dynamic rate in the High Cascades. Temperatures are commonly extreme, and freeze-thaw processes are active. Needle ice up to 15 cm high has been observed during frosty mornings of late summer. No doubt freeze-thaw processes contribute to substantial soil creep in the region. In addition, rock fall was heard virtually every day in the field.

PETROGRAPHIC CHARACTERISTICS OF VOLCANIC ROCKS

Minto Lavas

Basaltic Andesite of Hunts Cove. The rocks localized around Hunts Cove (Qv_1) are generally noritic (Thayer, 1937), but because their silica contents approach 53 percent, they are classified herein as basaltic andesite. One sample, SJ-19, collected by Sutton (1974), however, has a silica content of 52.27 percent, and a mineralogic composition showing basaltic characteristics.

Like most rocks affiliated with the Minto lavas, textures are generally seriate microporphyritic, grading into a fine grained, intergranular groundmass. In some, a weakly developed pilotaxitic structure occurs due to crude alignment of plagioclase microlites.

Plagioclase forms the largest phenocrysts and microphenocrysts, ranging from 1.4 mm to submicroscopic size. Anorthite content ranges from An_{15-60}. The larger microphenocrysts are commonly corroded and contain inclusions of olivine, magnetite and apatite.

Ferromagnesian minerals comprise subhedral and anhedral augite (up to 8 percent), subhedral and granular hypersthene, and small reddish olivine anhedra (1 to 3 percent). Hypersthene is the dominant pyroxene, but in some rocks is difficult to identify because of its granular form. More commonly, subhedral hypersthene occurs as poikilitic plates. Augite tends to be evenly divided throughout the rocks either as intergranular anhedra or stout prisms. It also occurs as reaction rims around olivine or as ragged poikilitic plates (Thayer, 1937, p. 1628). Olivine is commonly resorbed or variably altered to iddingsite or magnetite. Smaller olivine grains are also seen poikilitically enclosed by plagioclase or hypersthene. Magnetite is a common accessory as small, evenly distributed grains or as reaction products associated with olivine and the pyroxenes. Glass is rare or absent.

The lavas grade texturally and mineralogically into the conduit facies (plugs). Silica contents of these rocks lie between 53 and 54 percent, and textures vary from fine to coarse grained. The main distinguishing feature of the plug rocks is the dominance of hypersthene over augite by about one and one-half times leading to their classification as micronorites by Thayer (1937). Hypersthene forms subhedral prisms and augite tends to form large poikilitic plates and, less commonly, reaction rims around olivine or groundmass granules. Corroded olivine anhedra, up to 0.7 mm long, are rare. Plagioclase forms phenocrysts and microphenocrysts from 0.2 to 2.5 mm in length, and is zoned An_{5-60}.

Basaltic Andesite of Cathedral Rocks. Silica content for rocks of the Cathedral Rocks assemblage range from 54.75 to 56.50 percent (Fig. 11) establishing them as basaltic andesite. However, mineralogic compositions vary, especially with respect to the pyroxenes. There are strong mineralogic affinities with the Hunts Cove assemblage. The rocks are collectively fine grained, seriate microporphyritic, and weakly cumulophyric with rare glomerocrysts up to 3 mm in size. Groundmass compositions usually consist of tiny, fresh plagioclase laths set in among interstitial granular augite, magnetite, and rare hypersthene and iddingsite. Textures are finely intergranular, and some are incipiently pilotaxitic. Many are variably microvesicular. Samples 275 and 277 (Table III, Fig. 3) exemplify the general nature of the flow rocks (Qlc).

Plagioclase grades seriately from tiny subhedral microlites (An_{45-50}) to subhedral and euhedral phenocrysts zoned An_{30-86}. Plagioclase phenocrysts and microphenocrysts, from 0.2 to 1.0 mm in length, constitute up to 57 percent of the modal rock compositions, but they are not necessarily the largest constituents. The larger plagioclase crystals are evenly distributed in random arrangement whereas the smaller groundmass laths commonly show a weak subparallel alignment. The phenocrysts are

TABLE III

SELECTED PETROGRAPHIC DATA OF THE CATHEDRAL ROCKS

SAMPLE / UNIT	COLOR / ROCK TYPE	PHENOCRYSTS (Vol. %) / MATRIX (Vol. %)	PHENOCRYST SIZE (mm) / 2V: Plag	Cpx	Opx	Ol	Hb
275	Medium dark grey	40 total: 12 (0.5-2.0 mm)	$\leqslant$ 0.7	$\leqslant$ 0.8		0.5-1.5	
Q1c	Olivine basaltic andesite	59 (< 0.5 mm) 1 void		~40°		85°-90°	
MATRIX COMPOSITION: Tiny plagioclase laths and crystallites, interstitial granular clinopyroxene and magnetite, scattered iddingsite, and minor glass and trace of orthopyroxene.			TEXTURE: Generally fine grained, seriate, moderately porphyritic-densely microphyric, weakly cumulophyric (glomerocrysts $\leqslant$ 2 mm). Groundmass intersertal/intergranular, weakly pilotaxitic, weakly microvesicular.				
277	Dark grey	45 total: 25 (0.5-3.0 mm)	$\leqslant$ 1.0	$\leqslant$ 1.2		$\leqslant$ 1.0	
Q1c	Augite basaltic andesite	55 (< 0.2 mm)		30°-45°			
MATRIX COMPOSITION: Tiny plagioclase laths and microlites, interstitial granular and crystalline clinopyroxene and magnetite, minor granular orthopyroxene?			TEXTURE: Generally fine grained, marginally seriate, moderately microphyric - densely porphyritic, weakly cumulophyric (glomercrysts $\leqslant$ 3 mm). Groundmass intergranular.				

SAMPLE No. / MAP UNIT (MODAL %)	275 / Q1c		277 / Q1c
PHENOCRYSTS: (a)			
Plagioclase	35.0	....	41.1
Clinopyroxene	0.5 (h)		3.5 (i)
Orthopyroxene	---	....	---
Olivine (b)...........	4.5 (j)..		0.4
Hornblende (c)	---	....	---
Magnetite	---	....	---
TOTAL VOLUME %	40.0 (k)..		45.0 (1)
MATRIX: (d)			
Plagioclase	4.5	....	3.3
Clinopyroxene	0.4	....	1.5
Orthopyroxene	tr. (m)..		tr.?
Olivine (e)	0.3	....	---
Magnetite	4.9	....	9.9
Hematite	---	....	---
Dust, Opaques	47.4	....	40.3
Glass	1.5	....	---
Void	1.0	....	---
TOTAL VOLUME %	60.0	....	55.0
GRAND TOTAL VOLUME % .	100.0	....	100.0
REFRACTIVE INDEX	1.567	....	1.559
SILICA % (Fused Bead) ...	55.00	....	56.25
ANORTHITE (Microlites)(f)	35-49	(40)	19-49 (36)
ANORTHITE (Phenocrysts)(g)	50-67	....	55-73

fairly fresh, but some are corroded and contain poikilitic inclusions of olivine, as seen in sample 275 from an olivine basaltic andesite flow underlying Qil (Fig. 3).

Olivine and subordinate augite constitute the dominant ferromagnesian minerals in this assemblage. In some flows, however, hypersthene is more abundant than augite by about 2:1, as in the Hunts Cove assemblage. Olivine ($2V\gamma = 85^{\circ}$ to 90°), characteristically the largest phenocryst, occurs up to 1.5 mm in maximum dimension. Most occurs in subhedral or anhedral form, and is commonly corroded with granular iddingsite along margins and fractures. Many also have reaction rims of orthopyroxene, and contain inclusions of magnetite.

Augite ($2V\gamma = 30^{\circ}$ to 50°) forms subhedral and rare euhedral prisms up to 1 mm in length. The larger ones are typically fractured, and some have cores of olivine. Augite is also a common groundmass constituent, occurring subophitically or as interstitial granules (samples 96, 215, Fig. 3).

Hypersthene is generally a minor constituent, relegated either to the groundmass or as small (no greater than 1 mm), corroded or fractured, subhedral prisms. Samples 96 and 215 from two flows of olivine basaltic andesite - one capping the ridge to the south of Cathedral Rocks and the other cropping out on the east side of the ridge - are comparable to the rocks in the Hunts Cove assemblage in that hypersthene (about 1 percent) is twice as abundant as augite. Olivine, the dominant ferromagnesian phenocryst in both samples, ranges from 2 to 3 percent by volume. Sample 91, from a dike of augite basaltic andesite (Fig. 3), is mineralogically and texturally compatible with the flow rocks, especially sample 277 (Table III).

Volcanic Rocks Underyling North Cinder Peak. These rocks (Qv_2) are more variable in silica content than those of the Cathedral Rocks assemblage. The flow rocks vary between 54 and 55 percent silica (basaltic andesite) and a nearby vertical dike (samples 152, 153, Fig. 3; Appendix) has 57.50 percent silica (intermediate andesite).

One dacite flow (66 percent silica) was noted within this assemblage (sample 156, Fig. 3; Appendix). This rock has a coarse grained texture with phenocrysts and glomerocrysts of plagioclase ranging up to about 3 mm in size. Ferromagnesian minerals are small (no greater than 1 mm) and sparse, and are probably hypersthene. These phenocrysts, along with angular clasts (up to 0.5 mm) are set in an oxidized (pinkish), fine grained groundmass. In hand specimen it appears to be a crystal-lithic tuff, and is the only such rock noted within the study area.

Basaltic Andesite of Bear Butte. The augite basaltic andesite of Bear Butte ranges from 54.50 to 56.00

percent silica (Fig. 11), and is petrographically similar to the Hunts Cove assemblage. Flow rocks and dikes have phenocrysts and microphenocrysts of plagioclase (up to 51 percent), olivine (3 to 7 percent), and up to 2 percent augite set in a fairly dense, intersertal to intergranular groundmass. Generally, the flow rocks are graded seriately and are fine grained. Sparse glomerocrysts, however, occur up to 3 mm.

Sample 237 (Table IV, Fig. 3) represents the flow rocks (Qlb) making up the shield volcano. Euhedral to subhedral plagioclase forms fairly fresh, densely packed phenocrysts and microphenocrysts up to 2.5 mm long, with anorthite content ranging from An_{42-74}. Plagioclase associated with the groundmass exists as subhedral, commonly orthophyric laths composed of An_{31-35}.

Olivine ($2V_{\gamma} = 85^{\circ}$ to 90°), typically the dominant ferromagnesian phenocryst, occurs as intensly corroded and fractured anhedra and rare subhedra as large as 2.5 mm. In all samples olivine has altered to iddingsite in varying degrees; in some, alteration is total. Granular bowlingite occurs less commonly as an alteration product of olivine, and is usually confined to the groundmass. Some of the larger phenocrysts also exhibit pyroxene reaction rims, and contain inclusions of magnetite. Minor interstitial olivine is present in the groundmass and is mainly transformed to iddingsite and, to a lesser extent, bowlingite.

TABLE IV

SELECTED PETROGRAPHIC DATA OF BEAR BUTTE

SAMPLE / UNIT	COLOR / ROCK TYPE	PHENOCRYSTS (Vol. %) / MATRIX (Vol. %)	PHENOCRYST SIZE (mm) / 2V: Plag	Cpx	Opx	Ol	Hb
237	Medium grey	55 total: 25 (0.5-2.5 mm)	≤ 1.5	≤ 1.2	≤ 0.5	0.5-2.5	
Qlb	Augite basaltic andesite	43 (< 0.5 mm) 2 void		30°-45°		85°-90°	
MATRIX COMPOSITION: Plagioclase laths, clinopyroxene and some orthopyroxene crystals, interstitial granular magnetite, olivine, iddingsite and bowlingite? and dust.			TEXTURE: Fine to medium grained, densely porphyritic-extremely microphyric, strongly cumulophyric (glomerocrysts ≤ 3.0 mm), seriate. Intergranular/intersertal, slightly subophitic, weakly microvesicular (vesicles ≤ 0.2 mm), plagioclase slightly orthopyhric.				
231	Greyish black	45 total: 25 (0.5-2.5 mm)	0.2-2.5	≤ 0.6		0.5-1.0	
Qdb	Augite basaltic andesite	55 (< 0.3 mm)				~85°	
MATRIX COMPOSITION: Plagioclase laths and microlites, interstitial pyroxene, fibrous and granular magnetite, bowlingite?, iddingsite and minor amounts of glass, dust and olivine.			TEXTURE: Fine to medium grained, hiatal, moderately microphyric-densely porphyritic, weakly cumulophyric. Intersertal/intergranular, plagioclase moderately felted.				

SAMPLE No. / MAP UNIT (MODAL %)	237 / Qlb	231 / Qdb
PHENOCRYSTS:		
Plagioclase	51.0	40.7
Clinopyroxene	1.0 (a)	2.0
Orthopyroxene	0.6	---
Olivine	2.0 (b)	2.3 (c)
Hornblende	---	---
Magnetite	---	tr.
TOTAL VOLUME %	55.0 (d)	45.0 (e)
MATRIX:		
Plagioclase	17.1	32.2
Clinopyroxene	12.6	6.1
Orthopyroxene	0.7	---
Olivine	1.0	1.0
Magnetite	2.6	3.9
Hematite	---	---
Dust, Opaques	9.4	11.8
Glass	---	
Void	2.0	---
TOTAL VOLUME %	45.0	55.0
GRAND TOTAL VOLUME % .	100.0	100.0
REFRACTIVE INDEX	1.560	1.560
SILICA % (Fused Bead) ...	56.00	56.00
ANORTHITE (Microlites) ..	17-39 (31)	29-37 (34)
ANORTHITE (Phenocrysts) .	55-74	45-85

Augite ($2V\gamma = 30^{\circ}$ to 45°) occurs as subhedral prisms up to 1.2 mm long, but is only about one-third as abundant as olivine with which it is intimately associated. Anhedral augite consitutes the dominant groundmass mineral in an intergranular or mildly subophitic fashion.

Hypersthene forms rare subhedral prisms up to 0.5 mm, but is more typically confined to the groundmass in a granular mode or as tiny prisms. In all rocks observed, hypersthene is subordinate to augite.

Additional groundmass constituents include granular magnetite and dust. Sample 237, like many of the flow rocks, is mildly microvesicular.

The dike rocks (Qdb), represented by sample 231 (Table IV, Fig. 3), petrographically resemble the flow rocks in most cases, but differ as follows. Hypersthene is notably absent. Plagioclase phenocrysts seem to be slightly more calcic than the flow rocks, ranging from An_{27-85}. The larger olivine crystals exhibit the same degree of deterioration, but are more commonly altered to olive green to brownish, fibrous to granular bowlingite, prevalent, also, as a groundmass constituent. In some samples, alteration is so complete that only relic olivine remains. Mineralogic size grading in the dike rocks is somewhat more hiatal than the flows, and there is a stronger tendency for groundmass laths of andesine to occur in a felted manner. About 5 percent tachylitic glass is present within the groundmass.

Andesite of Sugar Pine Volcano. No petrographic data was obtained for the flow rocks and dikes of Sugar Pine volcano, Qls and Qds, respectively, but sample 258 (Table V, Fig. 3) from the conduit facies (Qcs) shows similarities with the plugs and flow rocks of the Hunts Cove assemblage. The plug rocks are seriately microphyric and, though fairly fine grained, are generally coarser than the flow rocks (Walker and others, 1966, p. D11). Like the Hunts Cove plugs, however, coarse facies probably exist within the Sugar Pine plug(s). One feature that distinguishes these rocks from other local members of the Minto lavas is their relatively higher silica contents (56.75 to 58.25 percent), classifying them predominantly as intermediate andesite (Fig. 11). Microphenocrysts of plagioclase, hypersthene and augite lie evenly distributed in a densely granular groundmass of andesine laths and crystallites, interstitial augite, hypersthene?, granular magnetite and other opaque materials.

The larger plagioclase phenocrysts, up to about 1 mm, are fairly fresh, euhedral to subhedral in habit, and are zoned An_{33-74}. Hypersthene phenocrysts (3 percent) exceed augite by 2:1, forming anhedral to subhedral prisms and equant crystals up to 0.4 mm in size. They are commonly fractured and contain inclusions of magnetite. Stubby

TABLE V

SELECTED PETROGRAPHIC DATA OF THE SUGAR PINE VOLCANO CONDUIT FACIES

SAMPLE / UNIT	COLOR / ROCK TYPE	PHENOCRYSTS (Vol. %) / MATRIX (Vol. %)	PHENOCRYST SIZE (mm) 2V Plag	Cpx	Opx	Ol	Hb
258	Dark grey	40 total: microphenocrysts	$\leqslant$ 1.1	$\leqslant$ 0.7	$\leqslant$ 0.4	$\leqslant$ 0.7	
Qcs	Hypersthene intermediate andesite	60 (< 0.1 mm)					

MATRIX: Plagioclase laths and crystallites, interstitial clinopyroxene and orthopyroxene? laths and grains, and granular magnetite.

TEXTURE: Fine grained, extremely microphyric, marginally hiatal. Intergranular.

SAMPLE No. / MAP UNIT (MODAL %)	258 / Qcs
PHENOCRYSTS:	
Plagioclase	34.4
Clinopyroxene	1.5
Orthopyroxene	3.0
Olivine	0.1
Hornblende	?
Magnetite	1.0
TOTAL VOLUME %	40.0 (a)
MATRIX:	
Plagioclase	13.1
Clinopyroxene	0.8
Orthopyroxene	3.4
Olivine	---
Magnetite	5.3
Hematite	---
Dust, Opaques	37.4
Glass	---
Void	---
TOTAL VOLUME %	60.0
GRAND TOTAL VOLUME % .	100.0
REFRACTIVE INDEX	1.549
SILICA % (Fused Bead) ...	58.25
ANORTHITE (Microlites) ..	20-52 (39)
ANORTHITE (Phenocrysts) .	33-74

subhedral augite crystals range up to 0.7 mm, and are commonly twinned along $\{100\}$. Both pyroxenes display moderate corrosion, and grade in size to groundmass proportions. Anhedral olivine forms rare phenocrysts but attains sizes of 0.7 mm in some rocks. Alteration to iddingsite and, to some degree, magnetite, is intense.

Andesite of North Cinder Peak

The rocks associated with North Cinder Peak are predominantly intermediate andesite, clustering between 57.50 and 58.00 percent silica (Fig. 11). Greene (1968), however, noted one rock from the conduit facies (sample MJW-96, Table VI, Fig. 3) with a silica content of about 56.25 percent. Except for localized coarse grained rocks and breccias within the plug, most rocks are fine grained microphyric and cumulophyric with individual crystals of plagioclase up to 2 mm in length. Most phenocrysts, however, are below 1.5 mm in size, and lie in a dense to vesicular, fine grained, intergranular groundmass of plagioclase microlites, interstitial augite, magnetite, and minor dust and glass. Samples 172 and 163 (Table VI) are typical of the flow rocks (Qln and, in part, Qnn).

Microphenocrysts and sparse phenocrysts comprise subhedral and euhedral plagioclase, augite, orthopyroxene and rare olivine anhedra, and make up about one-half the rock by volume. Plagioclase content ranges from An_{24-70}, and

TABLE VI

SELECTED PETROGRAPHIC DATA OF NORTH CINDER PEAK

SAMPLE / UNIT	COLOR / ROCK TYPE	PHENOCRYSTS (Vol. %) / MATRIX (Vol. %)	PHENOCRYST SIZE (mm) / 2V: Plag	Cpx	Opx	Ol	Hb
172	Medium grey	60 total: 40 (0.5-2.0 mm)	0.2-2.0	$\leqslant$ 1.5	$\leqslant$ 1.5	0.3-0.6	
Qnn (flow)	Augite intermediate andesite	40 (< 0.2 mm)					
MATRIX COMPOSITION: Plagioclase laths, interstitial clinopyroxene, granular magnetite, some crystallites, minor dust and glass.			TEXTURE: Generally fine grained, marginally hiatal, extremely porphyritic-moderately microphyric, mildly cumulophyric (glomerocrysts $\leqslant$ 2.0 mm). Intergranular, slightly subophitic, plagioclase mildly orthophyric-prismatic and aligned.				
163	Medium dark grey	55 total: 25 (0.5-2.0 mm)	< 0.8	$\leqslant$ 0.5	$\leqslant$ 0.3	< 0.5	
Qln	Augite intermediate andesite	44 (< 0.2 mm) 1 void		~35°			
MATRIX COMPOSITION: Plagioclase and clinopyroxene laths and microlites, interstitial granular magnetite, hematite, crystallites, minor dust and glass. Microvesicles.			TEXTURE: Generally fine grained, mildly hiatal, densely porphyritic-densely microphyric, strongly cumulophyric (glomerocrysts $\leqslant$ 2.0 mm). Intergranular/intersertal, slightly subophitic, plagioclase orthophyric-prismatic, mildly flow aligned, weakly microvesicular (vesicles < 1.0 mm).				
MJW-96	Color index = 24						
Qcn	Augite basaltic andesite	100 (0.1-0.8 mm)	Cpx (Wo:En:Fs) = 40:37:23 Opx (Fs) = 25 (bronzite)				
NOTE: Sample from Greene, 1968.			TEXTURE: Granular.				

SAMPLE No. / MAP UNIT (MODAL %)	172 / Qnn (a)		163 / Qln		MJW-96 (b) / Qcn
PHENOCRYSTS:					
Plagioclase	55.2	....	50.4	....	---
Clinopyroxene	2.0	....	2.0 (c)..		---
Orthopyroxene	2.5	....	2.3	....	---
Olivine	0.3	....	0.3	....	---
Hornblende	---	....	---	....	---
Magnetite	---	....	---	....	---
TOTAL VOLUME %	60.0 (d)..		55.0 (e)..		--- (f)
MATRIX:					
Plagioclase	5.4	....	12.2	....	72.5
Clinopyroxene	12.4	....	6.1	....	12.5
Orthopyroxene	0.3	....	0.1	....	7.1
Olivine	---	....	---	....	---
Magnetite	4.9	....	3.8	....	3.6
Hematite	---	....	1.0	....	---
Dust, Opaques	16.5	....	19.3	....	---
Glass	0.5	....	1.5	....	3.4
Void	---	....	1.0	....	---
TOTAL VOLUME %	40.0	....	45.0	....	99.1 (g)
GRAND TOTAL VOLUME % .	100.0	....	100.0	....	100.0
REFRACTIVE INDEX	1.551	....	---	....	1.559
SILICA % (Fused Bead) ...	57.75	....	57.50 (h).		56.25 (i)
ANORTHITE (Microlites) ..	26-43 (33)		34-41 (36)		67 (j)
ANORTHITE (Phenocrysts) .	62	....	24-67	....	---

the larger crystals are mildly corroded and contain dusty inclusions. Plagioclase associated with the plug (Qcn) is fresher than that of the associated flow rocks.

The pyroxenes occur as phenocrysts in nearly equal quantities of about 2.0 to 2.5 percent. Augite ($2V\gamma = 35^{\circ}$) exists commonly as twinned, stout prisms up to 1.5 mm. Comparable-sized orthopyroxene forms prismatic laths. Both range from fresh to moderately corroded and commonly have a granular appearance. Thin reaction rims of hornblende? are present around some of the pyroxenes. Composition of the orthopyroxene in the conduit rocks is intermediate bronzite (Greene, 1968, p. G29). Rare olivine ranges from moderately fresh to severely corroded crystals largely altered to iddingsite. Like plagioclase, olivine tends to be fresher in the conduit facies.

Groundmass plagioclase forms stubby to elongate microlites ranging in composition from An_{41-53}, and are moderately flow aligned in some rocks. In flow rocks particularly, microlites are mildly subophitically enclosed by augite. Orthopyroxene occurs in amounts no greater than 0.3 percent in the groundmass, although Greene (1968, p. G29-31) notes up to 7.1 percent in a rock from the plug (sample MJW-96). Much of this orthopyroxene, however may be in the form of microphenocrysts.

Mount Jefferson

Basaltic Andesite and Andesite Lavas of the Main Cone. The bulk of Mount Jefferson is composed of densely porphyritic flows of augite basaltic and intermediate andesite. These lavas (Qmj) range in silica content from 54.50 to 58.25 percent (Fig. 11).

Phenocrysts of euhedral plagioclase zoned from sodic andesine to sodic bytownite occur up to 2 mm in length. Most are fairly fresh, but some have corroded margins. Euhedral to subhedral augite up to 0.5 mm long composes 6 to 8 percent of the rocks by volume, whereas hypersthene ranges from only 1 to 2 percent. Hypersthene tends to form both larger (0.5 to 1.5 mm) and more euhedral phenocrysts than augite. They typically occur as long prisms rivaling the plagioclase phenocrysts in size. The pyroxenes in these rocks differ markedly from the later more silicic Mount Jefferson lavas (Qsj) by showing relatively little peripheral oxidation. Small olivine anhedra, ranging from 0.5 to 1.0 mm, form up to 5.7 percent, but normally less, of the rock volume. In some rocks where olivine is more abundant, it occurs as plates up to 3 mm in maximum dimension. The anhedra are only partially altered to magnetite around their margins, whereas smaller olivine granules are relatively fresh.

The phenocrysts characteristically lie in a dense, glassy to holocrystalline matrix of plagioclase microlites, granular pyroxene, magnetite and glass. The rocks are cumulophyric, with glomerocrysts of augite, plagioclase and olivine.

<u>Second Stage Dacitic Andesite</u>. These lavas (Qsj) are higher in silica content (about 60.00 to 61.50 percent) (Fig. 11) than the preceding lavas, and were classified as silicic andesite by Sutton (1974). In the present scheme, they are classified as hypersthene dacitic andesite. Sample MJW-105 (Greene, 1968) given in Table VII outlines some of the rock characteristics.

Euhedral hypersthene, up to 2 mm long, forms the dominant ferromagnesian phenocryst making up to 9 and commonly 5 percent of the rock by volume. Some hypersthene contains inclusions of plagioclase and magnetite. Augite phenocrysts (up to 1 mm) rarely exceed 8 percent by volume, and tend to diminish with increasing silica content. Both pyroxene types show a preferential prismatic habit as phenocrysts. Augite displays granular altered borders of magnetite and orthopyroxene. In some rocks, hypersthene phenocrysts contain corroded olivine cores. Olivine occurs only as a minor constituent in these rocks as oxidized phenocrysts or as granular anhedra within the groundmass. The presence of oxyhornblende

TABLE VII

SELECTED PETROGRAPHIC DATA OF MOUNT JEFFERSON SECOND STAGE LAVAS

SAMPLE / UNIT	COLOR / ROCK TYPE	PHENOCRYSTS (Vol. %) / MATRIX (Vol. %)	PHENOCRYST SIZE (mm) / 2V				
			Plag	Cpx	Opx	Ol	Hb
MJW-105	Color index = 28	62 total	Phenocrysts 0.1-1.5 mm				
Qsj	Hypersthene dacitic andesite	34 (< 0.1 mm) 4 void	Opx (Fs) = 37 (hypersthene)				

MATRIX COPOSITION: Plagioclase and magnetite grains in brown glass.
NOTE: Sample from Greene, 1968 (silicic andesite).

TEXTURE: Porphyritic, intersertal.

SAMPLE No. / MAP UNIT (MODAL %)	MJW-105 (a) / Qsj
PHENOCRYSTS:	
Plagioclase	44.6
Clinopyroxene	0.5
Orthopyroxene	15.1
Olivine	---
Hornblende	0.2
Magnetite	1.6
TOTAL VOLUME %	62.0
MATRIX:	
Plagioclase	---
Clinopyroxene	---
Orthopyroxene	---
Olivine	---
Magnetite	---
Hematite	---
Dust, Opaques	---
Glass	34.0
Void	4.0
TOTAL VOLUME %	38.0
GRAND TOTAL VOLUME %	100.0
REFRACTIVE INDEX	1.534
SILICA % (Fused Bead)	61.00
ANORTHITE (Microlites)	---
ANORTHITE (Phenocrysts)	62

(up to 3 percent) also distinguishes the Second Stage lavas from the earlier Main Cone lavas. It forms stout, subhedral prisms to highly altered anhedra which have exsolution rims of granular magnetite, especially in contacts within the groundmass. Oxyhornblende is pleochroic red to brown, and commonly poikilitically encloses altered augite, hypersthene, olivine and plagioclase. Plagioclase forms euhedral phenocrysts as large as 2.5 mm of which some of the larger ones are embayed and contain magnetite inclusions. Most plagioclase is zoned An_{15-85} (Thayer, 1973). According to Sutton (1974), however, the larger phenocrysts associated with rocks near 60 percent silica are labradorite, and groundmass-related laths range from An_{34} to An_{44}.

The matrix is composed of plagioclase microlites interwoven in a felted to pilotaxitic arrangement with interstitial pyroxene, magnetite, moderately abundant brownish glass and minute crystallites. Textures vary from intersertal to intergranular, and glomerocrysts comprising combinations of all phenocryst minerals are common.

Dacitic Andesite Intracanyon Flow North of Cathedral Rocks

This approximately 100 m-thick flow (Qil) varies between hornblende-pyroxene intermediate and dacitic andesite, with silica content ranging from 59.75 to 61.00

(Fig. 11). It is represented by sample 67 (Table VIII, Fig. 3).

Phenocrysts make up about 20 percent of the rock by volume. The rock is fine to medium grained, and mildly cumulophyric with glomerocrysts up to 5 mm in some samples.

Fresh, subhedral and euhedral plagioclase forms the largest phenocrysts, but some show mild corrosion as the 3 mm maximum size is approached. Anorthite composition varies from An_{55-87}.

Hypersthene and oxyhornblende are the dominant ferromagnesian phenocrysts, occurring in approximately equal amounts of 2.0 to 2.5 percent. Fairly fresh, prismatic hypersthene varies between 0.4 and 2.5 mm in size. Prismatic oxyhornblende is rarely longer than 7 mm, and, unlike the Mount Jefferson Second Stage lavas, is altered almost completely to pseudomorphic magnetite. The peripheral magnetite is granulated, and the pseudomorph interiors show intense corrosion and poikilitic inclusions of pyroxene, plagioclase and magnetite.

Rare olivine occurs as subhedral to anhedral phenocrysts up to 2 mm in size. Augite is notably absent as phenocrysts but occurs within the groundmass as small, intergranular crystals, or subophitically enclosing orthophyric to elongate plagioclase microlites of calcic andesine.

TABLE VIII

SELECTED PETROGRAPHIC DATA OF THE INTRACANYON FLOW NORTH OF CATHEDRAL ROCKS

SAMPLE / UNIT	COLOR / ROCK TYPE	PHENOCRYSTS (Vol. %) / MATRIX (Vol. %)	PHENOCRYST SIZE 2V Plag	Cpx	Opx	Ol	Hb
67	Light grey	20 total	≤ 2.0	≤ 1.0	0.4-1.5		≤ 1.5
Qil	Hornblende-pyroxene intermediate andesite	80 total					

MATRIX COMPOSITION	TEXTURE
Plagioclase laths and microlites, prisms and grains of clinopyroxene?, and orthopyroxene, interstitial magnetite.	Fine to medium grained, moderately porphyritic, mildly cumulophyric (glomerocrysts ≤ 3.0 mm), marginally seriate. Intergranular, slightly subophitic, moderately felted, plagioclase slightly orthophyric.

SAMPLE No. / MAP UNIT (MODAL %)	67 / Qil
PHENOCRYSTS:	
Plagioclase	15.4
Clinopyroxene	---
Orthopyroxene	2.5
Olivine	0.1
Hornblende	2.0
Magnetite	---
TOTAL VOLUME %	20.0
MATRIX:	
Plagioclase	59.0
Clinopyroxene	2.8
Orthopyroxene	1.1
Olivine	---
Magnetite	1.9
Hematite	---
Dust, Opaques	15.2
Glass	---
Void	---
TOTAL VOLUME %	80.0
GRAND TOTAL VOLUME % .	100.0
REFRACTIVE INDEX	1.541
SILICA % (Fused Bead) ...	59.75
ANORTHITE (Microlites) ..	16-45 (31)
ANORTHITE (Phenocrysts) .	55-87

The plagioclase microlites are commonly arranged in a felted manner within the groundmass. The remaining groundmass comprises intergranular magnetite, and prisms and equant grains of hypersthene. Except for rare glass and alteration of oxyhornblende and augite phenocrysts, the intracanyon flow lies within the petrographic variability seen among the Mount Jefferson Second Stage lavas.

Goat Peak Volcano

Table Lake Lava Flows of Intermediate Andesite.

The consanguinous Table Lake lavas of intermediate andesite (Qta_{1-4}) petrographically resemble the intracanyon flow (Qil). The range of silica content, however, is slightly lower, varying between about 57.00 and 60.00 percent (Fig. 11). Qta_1 and Qta_2 appear to be somewhat higher in silica than the younger Qta_3 and Qta_4, in consistence with their respective mineralogic compositions (Table IX).

Except for Qta_4, these lavas are collectively dense, fine to medium grained, porphyritic with phenocrysts making up 15 to 20 percent of the rock volume. Phenocrysts comprise normal and oscillatory-zoned, subhedral to euhedral plagioclase (An_{30-87}), subhedral prisms of hypersthene, oxidized prismatic oxyhornblende, and anhedral

TABLE IX

SELECTED PETROGRAPHIC DATA OF THE TABLE LAKE LAVA FLOWS

SAMPLE / UNIT	COLOR / ROCK TYPE	PHENOCRYSTS (Vol. %) / MATRIX (Vol. %)	PHENOCRYST SIZE (mm) / 2V: Plag	Cpx	Opx	Ol	Hb
239	Medium grey	15 total	≤ 2.0	≤ 0.4	≤ 0.8	≤ 1.7	≤ 2.0
Qta_1	Augite intermediate andesite	85 total				~90°	
MATRIX COMPOSITION: Plagioclase laths, clinopyroxene grains and crystals, some interstitial granular magnetite and olivine.			TEXTURE: Fine to medium grained, moderately porphyritic, mildly cumulophyric (glomerocrysts 0.8-3.0 mm), marginally seriate. Intergranular/subophitic, pilotaxitic.				
139	Light grey	25 total	0.1-2.0	≤ 0.8	≤ 0.6	≤ 0.6	0.2-5.0
Qta_2	Pyroxene-hornblende intermediate andesite	75 total					
MATRIX COMPOSITION: Plagioclase laths and microlites surrounded by orthopyroxene laths, some clinopyroxene, interstitial granular magnetite and dust, minor glass and rare olivine.			TEXTURE: Fine to medium grained, densely porphyritic, mildly cumulophyric (glomerocrysts ≤ 4.0 mm), hiatal. Intergranular/subophitic, moderately pilotaxitic.				
MJW-97	Color index = 23	0.6 total					
Qta_2?	Hypersthene basaltic andesite	99.4 (0.1-1.5 mm)	Cpx (Wo:En:Fs) = 37:18:45 Opx (Fs) = 43 (hypersthene)				
NOTE: Sample from Greene, 1968 ("intrusive andesite"). Low color index indicates low inferred silica content.			TEXTURE: Granular, generally coarse.				
11	Light greenish grey	1.7 total	0.4-2.0		≤ 0.5	0.4-1.3	
Qta_4	Augite intermediate andesite	98.3 total					
MATRIX COMPOSITION: Tiny plagioclase laths, interstitial granules of magnetite and pyroxene (clinopyroxene?), dust and minor glass.			TEXTURE: Chiefly aphanitic, generally aphyric, hiatal, rarely cumulophyric (glomerocrysts ≤ 0.3 mm). Weakly intergranular to subophitic. Strongly pilotaxitic.				

SAMPLE No. / MAP UNIT (MODAL %)	239 / Qta_1	139 / Qta_2	MJW-97 (a) / Qta_2?	11 / Qta_4
PHENOCRYSTS:				
Plagioclase	12.4	13.9	---	0.8
Clinopyroxene	0.4	0.2	---	---
Orthopyroxene	1.0	0.9	---	0.5
Olivine	0.6	0.6	0.6	0.1
Hornblende	0.6 (b)	8.8	---	0.3
Magnetite	---	0.6	---	---
TOTAL VOLUME %	15.0	25.0	0.6	1.7
MATRIX:				
Plagioclase	56.3	36.8	76.9	61.9
Clinopyroxene	22.4	6.2	7.8	16.0
Orthopyroxene	0.3	4.3	13.3	1.8
Olivine	0.2	0.1	---	---
Magnetite	1.9	5.0	1.4	2.0
Hematite	---	---	---	---
Dust, Opaques	2.9	12.6	---	13.6
Glass	1.0	10.0	---	3.0
Void	---	---	---	---
TOTAL VOLUME %	85.0	75.0	99.4 (c)	98.3
GRAND TOTAL VOLUME %	100.0	100.0	100.0	100.0
REFRACTIVE INDEX	1.550	1.541	1.570	1.544
SILICA % (Fused Bead)	58.00	59.75	54.50 (d).	59.25
ANORTHITE (Microlites)	19-40 (32)	16-38 (28)	54	27-42 (35)
ANORTHITE (Phenocrysts)	33-81	52-87	---	74-97 ?

olivine ($2V\gamma = 85^{\circ} - 90^{\circ}$). Augite ($2V\gamma \approx 50^{\circ}$) forms rare phenocrysts but occurs commonly as a major groundmass constituent in some rocks as tiny laths or subophitic plates.

Hypersthene phenocrysts rarely exceed 1 mm in size. Oxyhornblende forms prisms as long as 5 mm but more commonly up to 3 mm. Olivine rarely exceeds 1.5 mm in only a few cases. Augite ranges up to 0.8 mm. Phenocrysts cluster variably to form sporadic glomerocrysts up to 6 mm in size.

The groundmass of these rocks is typically a dense, intergranular to subophitic arrangement of plagioclase microlites and pyroxene, interstitial granular magnetite, minor glass and rare olivine. The fabric is commonly felted or pilotaxitic.

Each of the flows is characterized by a variable but predominant suite of ferromagnesian phenocrysts. With the partial exception of oxyhornblende, phenocrysts tend to occur in small amounts. Qta_1 characteristically has hypersthene and oxyhornblende in about equal quantities of about 1 percent with proportionally less olivine. Augite is rare. Qta_2 is dominated by 5 to 9 percent oxyhornblende, and has 1.0 to 2.5 percent hypersthene, 0.5 to 1.0 percent olivine and rare augite. In Qta_3 olivine and oxyhornblende dominate augite by about 2:1 percent. Qta_4 differs greatly from the others in that it is fine grained with rare phenocrysts making up only to 1.7 percent of the total rock volume. Generally, hypersthene dominates over nearly equal amounts of olivine and oxyhornblende.

Qta_1 is represented by sample 239 (Table IX, Fig. 3). Euhedral plagioclase, zoned An_{33-81}, ranges up to 2 mm in size. These phenocrysts are commonly moderately corroded, and poikilitically envelop small grains of magnetite and orthopyroxene. Subhedral, prismatic hypersthene, up to 0.8 mm, is slightly more abundant than the other ferromagnesian minerals, but any, individually, rarely exceeds more than 1 percent of the rock volume as phenocrysts. Hypersthene is pleochroic pink (α) to pale green (γ), and is commonly embayed with inclusions of magnetite and small cores of olivine. Olivine phenocrysts occur as peripherally embayed and fractured anhedra up to 1.7 mm in size, and have $2V_{\gamma} \approx 90°$. Tiny granular inclusions of magnetite are common and some have incipient margins of orthopyroxene. Sporadic iddingsite also forms along the margins and fractures of olivine. Euhedral prisms and anhedral grains of relic oxyhornblende are sparsely scattered throughout the rock. Virtually all oxyhornblende exists as pseudomorphic magnetite with granulated margins. These granules are made up of magnetite and clinopyroxene. The groundmass is a coarse arrangement of slender andesine laths enclosed in an intergranular to subophitic matrix of subhedral and anhedral, granular augite (with rare hypersthene? cores), granular magnetite and small amounts of olivine. The fabric is mainly pilotaxitic.

Qta_2 and Qta_3 resemble Qta_1 except for relative ferromagnesian mineral abundances. Qta_2 (sample 139; Table IX, Fig. 3) is mainly distinguished by oxyhorn-blende, up to 5 mm long, occurring as the principle ferromagnesian phenocryst (about 9 percent). Oxyhornblende has sporadic inclusions of orthopyroxene, plagioclase and granular magnetite, and some pseudomorphs are broken. Among the pseudomorphs, magnetite has replaced previously broken oxyhornblende crystals. Hypersthene (about 1 percent) is dominant over both augite and olivine. Olivine tends to be more subhedral than in Qta_1. Plagio-clase phenocrysts are zoned An_{52-87} and the microlites, An_{38}. The groundmass is finer grained than Qta_1 and contains, at least locally, more interstitial glass.

Sample MJW-97 (Greene, 1968) (Table IX, Fig. 3) comes from a lobar feature above Hole-in-the-Wall Park mapped as an intrusion (plug) as inferred by the coarse grained texture (Greene, 1968, p. G29-31; written communication, 1974). Mapped here as Qta_2, sample MJW-97 does appear to differ markedly from the normal format of the Table Lakes lavas. It is composed of plagioclase (sodic labradorite), iron-rich ferroaugite, hypersthene -

all as groundmass constituents - and 6 percent olivine as phenocrysts. Grain size ranges from 0.1 to 1.5 mm, and was noted by Greene as the coarsest rock in the area. The rock contains no oxyhornblende which is otherwise present in varying amounts in the sequence, and yielded a silica content of 54.50 percent. This silica content is low with respect to the associated rocks and, according to Greene, is attributable to an apparently high iron content affecting the refractive index measurement.

Qta_3 has greenish to reddish olivine (up to 2 percent) as the dominant ferromagnesian phenocryst, and equals oxyhornblende in abundance. Augite ($2V\gamma \approx 50^{\circ}$) occurs only rarely as phenocrysts. Texturally, this rock resembles the others.

Qta_4, represented by sample 11 (Table IX, Fig. 3) is fine grained, aphyric pyroxene intermediate andesite. Extremely sparse phenocrysts make up only about 1 percent by volume, imparting a strongly hiatal texture to the rock. The phenocrysts comprise 0.2 to 2.5 mm euhedral plagioclase (zoned An_{60-87}), hypersthene up to 0.5 mm, and very rare olivine, with $2V\gamma = 85^{\circ} - 90^{\circ}$, up to 1.3 mm. In some rocks, oxyhornblende equals or slightly exceeds olivine in abundance. Phenocryst condition is like that of the other members, but larger plagioclase crystals do show intense corrosion. Hypersthene and olivine are both relatively fresh, although some hypersthene shows peripheral corrosion. The phenocrysts are set in a very fine grained, dense, intergranular groundmass of strongly flow aligned plagioclase microlites, interstitial granular magnetite, pyroxene (mostly augite) and minor glass. The oriented plagioclase microlites (An_{39-43}) conform to the well-developed platy structure of the lava.

Goat Peak Dacite. The hornblende dacite flows ($Qlg_{1,\ 2}$) range from 63.25 to 70.75 percent silica, making them the most siliceous rocks in the study area (Fig. 11). The Goat Peak plug (Qcg) varies between about 67.50 and 68.00 percent silica (Sutton, 1974; Appendix), and the adjacent fragmental material (Qng) is slightly more silicic, ranging from 69.75 to 70.75 percent. There is an apparent demarcation in silica values associated with the two lava flows. The older (Qlg_1) has a silica content of 67.00 to 70.00 percent, and the younger (Qlg_2) ranges between 63.25 and 64.50 percent (Fig. 11).

Except for the fragmental unit (Qng), the rocks associated with the Goat Peak dacite sequence are fine to medium grained, hiatal-porphyritic and moderately cumulophyric. Subhedral and euhedral phenocrysts include 10 to 27 percent plagioclase, 2.5 to at least 4.5 percent oxyhornblende and 0.5 to 1.5 percent hypersthene. Augite and olivine are rare as phenocrysts. Sutton (1974, p. 39) noted that olivine, augite and hypersthene contents decrease as hornblende increases in these rocks, indicating mineral replacement to be a result of both crystallization phase and alteration during crystallization (Figs. 7, 8). This same relationship is noted in the Table Lake lavas as well.

The groundmass consists of microlithic plagioclase in a matrix of abundant granular magnetite, opaques, and clear, pinkish or brownish glass. Groundmass textures are predominantly intersertal to hyalopilitic, and commonly display felted or pilotaxitic fabrics.

The plug of Goat Peak (Qcg), also described by Sutton (1974) is represented by sample 42 (Table X, Fig. 3). Plagioclase forms the largest phenocrysts, up to 5 mm in rare cases, but more typically, no greater than 1.5 mm. Anorthite contents range from An_{40-48}, but Sutton reported compositions of An_{2-34}, with the majority being An_{10-19}. The crystals range from fresh to internally corroded, and some of the larger plagioclase phenocrysts have poikilitic inclusions of magnetite, pyroxene and glass.

Oxyhornblende is the dominant ferromagnesian phenocryst, forming severely corroded prisms up to 3 mm long. It is pleochroic greenish yellow or gold (α) to deep red or brownish red (γ), and is peripherally altered to magnetite, but not to the extent seen in the Table Lakes lavas. Like the plagioclase phenocrysts, poikilitic inclusions of magnetite, pyroxene and glass are common. Among the glomerocrysts, oxyhornblende is

TABLE X

SELECTED PETROGRAPHIC DATA OF THE GOAT PEAK DACITE

SAMPLE / UNIT	COLOR / ROCK TYPE	PHENOCRYSTS (Vol. %) / MATRIX (Vol. %)	PHENOCRYST SIZE (mm) 2V Plag	Cpx	Opx	Ol	Hb
42	Pinkish grey	28 total	0.2-5.0		≤ 0.5		≤ 3.0
Qcg	Hornblende dacite	72 total					
MATRIX COMPOSITION: Tiny plagioclase laths and microlites, interstitial granular magnetite, acicular hematite, glass and dust, crystallites and rare pyroxene.		TEXTURE: Fine to medium grained, marginally hiatal, densely porphyritic, strongly cumulophyric (glomerocrysts ≤ 4.0 mm). Intergranular/intersertal, moderately felted to pilotaxitic, slightly porous.					
207	Whitish grey	20 total	0.3-2.0		≤ 1.7		0.2-3.0
Qlg_1	Hornblende dacite	80 total					
MATRIX COMPOSITION: Plagioclase laths, abundant interstitial clear glass and dust, some magnetite and pyroxene?		TEXTURE: Fine to medium grained, hiatal, moderately porphyritic, mildly cumulophyric (glomerocrysts ≤ 3.0 mm). Intergranular/hyalopilitic, moderately pilotaxitic to felted.					
210	Blackish grey	14 total	0.2-3.0		≤ 0.8		0.3-2.0
Qlg_2	Hornblende dacite	86 total					
MATRIX COMPOSITION: Tiny plagioclase laths and microlites, interstitial granular dust, magnetite, pink glass and crystallites.		TEXTURE: Fine to medium grained, moderately porphyritic, mildly cumulophyric (glomerocrysts ≤ 4.0 mm), hiatal. Hyalopilitic/intergranular, pilotaxitic and fluidal banded.					

SAMPLE No. / MAP UNIT (MODAL %)	42 / Qcg	207 / Qlg_1	210 / Qlg_2
PHENOCRYSTS:			
Plagioclase	23.3	14.6	8.7
Clinopyroxene	---	0.4	0.1
Orthopyroxene	0.9	0.6	1.0
Olivine	---	tr.	---
Hornblende	2.8	2.9	3.7
Magnetite	1.0 (a)	1.5 (b)	0.5 (c)
TOTAL VOLUME %	28.0	20.0	14.0
MATRIX:			
Plagioclase	4.8	34.8	35.6
Clinopyroxene	0.3	tr.	---
Orthopyroxene	---	tr.	---
Olivine	---	---	---
Magnetite	4.5	2.8	3.3
Hematite	39.4	---	---
Dust Opaques	15.0	42.4	47.1
Glass	8.0		
Void	---	---	---
TOTAL VOLUME %	72.0	80.0	86.0
GRAND TOTAL VOLUME %	100.0	100.0	100.0
REFRACTIVE INDEX	1.508	1.508	1.520
SILICA % (Fused Bead)	68.00	68.00	64.50
ANORTHITE (Microlites)	10-24 (20)	16-27 (22)	19-25 (22)
ANORTHITE (Phenocrysts)	40-48	34-58	33-81

moderately invaded by plagioclase. At these junctures oxyhornblende margins are unaltered, indicating oxidation to be a post-eruptive phenomenon. Secondary alteration to hematite is also seen along the margins of some oxyhornblende crystals.

Hypersthene occurs as subhedral crystals and irregular prisms up to 0.5 mm long with reaction rims of oxyhornblende which, in turn, are altered to magnetite. Like oxyhornblende, hypersthene phenocrysts are severely corroded.

Olivine and augite are rare. Generally, any augite present is confined to the groundmass or associated with other minerals as small clots.

The groundmass is mainly a clotted aggregate of dust, glass, granular magnetite, and fibrous or acicular hematite enclosing short plagioclase microlites (An_{24}). The texture is predominantly intersertal with a felted fabric.

The flows (Qlg_1 and Qlg_2) appear to be consanguinous with Goat Peak, and are represented by samples 207 and 210, respectively (Table X, Fig. 3). In Qlg_1 oxyhornblende phenocrysts are heavily oxidized, and are mostly broken and corroded. Rare augite and olivine with pyroxene reaction rims are also present as phenocrysts (no greater than 0.4 percent). Locally, particularly in the upper oxidized portions of the flow, the rock has a pinkish color (e.g., sample 15, Fig. 3) due to abundant fibrous and acicular hematite in the groundmass, and bordering oxyhornblende and hypersthene crystals. The degree of oxidation, and the amount of hematite, apparently affects the pleochroism of the oxyhornblende, becoming redder (γ) with increasing hematite. Some of the less oxidized oxyhornblende have small cores and inclusions of orthopyroxene.

Plagioclase phenocrysts in the flows seem to be more calcic than in Goat Peak proper, ranging from An_{33-63+}. Slender microlites (An_{28}) are comparable to those in Goat Peak. The groundmass contains much more clear glass than rocks of the plug, and has minute crystallites (scopulites?) of pyroxene resulting in a near-hyalopilitic texture.

Oxyhornblende in the younger, less silicic flow (Qlg_2) is corroded, and is not oxidized to the extent seen in Qlg_1. Similarly, hypersthene has a fresher appearance. Pronounced flow layering of the plagioclase microlites (An_{25}) is apparent in the groundmass, imparting a pilotaxitic fabric to the rock. Interstitial glass tends to be more pinkish than the earlier flow which, with the more abundant intergranular opaque materials, probably contribute to the darker color of the rock.

Dacitic Andesite "Dome" Southwest of Goat Peak

This small dome-like feature (Qdm) has some petrographic similarities to Goat Peak, but no other relationship is apparent. The rock has phenocrysts and glomerocrysts composing 7 to 15 percent of the rock volume. In terms of silica content, 61.50 to 63.00 percent (Fig. 11), it is dacitic andesite.

Phenocrysts comprise 4 to 10 percent euhedral and subhedral pyroxene (probably hypersthene) up to 1.5 mm, and 1 to 3 percent oxyhornblende prisms as long as 7 mm. Glomerocrysts commonly reach 3 mm in maximum dimension. The groundmass is fine grained and glassy, with a granular, pilotaxitic texture.

Intermediate Andesite of Patsy Lake Volcano

Except for minor textural and compositional variations, the rocks of this assemblage are predominantly augite intermediate andesite, ranging in silica content from 57.00 to 58.75 percent (Fig. 11).

The rocks are collectively fine to medium grained, hiatal-porphyritic and cumulophyric, with a fine grained, commonly glassy groundmass. Plagioclase phenocrysts are zoned An_{25-81}, and range up to 3 mm in size. Either augite, hypersthene or, more rarely, olivine, occurs as the chief ferromagnesian phenocryst, making up to 19 percent of the rock volume. Olivine, as seen in sample 238 (Fig. 3), has $2V_{\gamma} \approx 85°$, and augite has $2V_{\gamma} = 50° - 55°$. Plagioclase microlites are typically composed of intermediate andesine (An_{39-42}).

Conduit Facies. The plug rock (Qcp) is represented by sample 7 (Table XI, Fig. 3). Plagioclase is about equally distributed in the groundmass and as phenocrysts. The latter occurs as euhedral crystals up to 3 mm, zoned An_{33-78}. Inclusions of magnetite and pyroxene are common in the larger, more corroded plagioclase phenocrysts.

Anhedral crystals and stubby prisms of augite (up to 1.5 mm) make up about 6 percent of the phenocrysts, predominating more subhedral hypersthene by about 2:1. Hypersthene tends to form larger crystals (up to 2 mm), and is mildly corroded and fractured with small poikilitic inclusions of plagioclase. Both augite and hypersthene combine to form glomerocrysts as large as 4 mm.

Moderately fractured and corroded, anhedral olivine, displaying thin reaction rims of pyroxene, forms rare phenocrysts no larger than 1 mm in size. Small amounts of pseudomorphic magnetite (after oxyhornblende?) form euhedral prisms rarely exceeding 0.4 mm in length.

The groundmass is composed of a felted array of elongate prisms and orthophyric andesine microlites (An_{40}) set in an extremely glassy matrix. Brownish glass makes up about one-half the groundmass (35.7 percent), and is accompanied by interstitial augite?, angular to sub-rounded magnetite polyhedra and opaque materials. The texture is chiefly hyalopilitic.

TABLE XI

SELECTED PETROGRAPHIC DATA OF PATSY LAKE VOLCANO

SAMPLE / UNIT	COLOR / ROCK TYPE	PHENOCRYSTS (Vol. %) / MATRIX (Vol. %)	PHENOCRYST SIZE (mm) 2V Plag	Cpx	Opx	Ol	Hb
7	Blackish grey	28 total	0.2-3.0	$\leq$ 1.5	$\leq$ 2.0	$\leq$ 1.0	$\leq$ 0.4
Qcp	Augite intermediate andesite	70 2 void					
MATRIX COMPOSITION: Plagioclase laths, abundant brown glass, interstitial minor clinopyroxene, crystallites and dust.			TEXTURE: Fine to medium grained, marginally hiatal, densely porphyritic, strong-cumulophyric (glomerocrysts $\leq$ 4.0 mm), slightly microvesicular (vesicles $\leq$ 0.5 mm). Intergranular/hyalopilitic, plagioclase slightly orthophyric.				
134	Medium grey	15 total	0.2-3.0		$\leq$ 1.5	$\leq$ 1.5	
Qlp	Augite intermediate andesite	85 total					
MATRIX COMPOSITION: Slender plagioclase microlites, interstitial grains and prisms of clinopyroxene, minor orthopyroxene, granular magnetite, some dust and glass.			TEXTURE: Fine to medium grained, hiatal, moderately porphyritic, mildly cumulophyric (glomerocrysts ~ 1.0-3.0 mm). Intergranular/subophitic, mildly pilotaxitic.				
187	Blackish grey	25 total	0.2-3.0	$\leq$ 1.6	$\leq$ 1.6	$\leq$ 2.0	
Qlp	Augite intermediate andesite	68 7 void					
MATRIX COMPOSITION: Plagioclase microlites, tiny crystals and granules of pyroxene with interstitial dust and fairly abundant brownish glass.			TEXTURE: Fine to medium grained, hiatal, densely porphyritic, mildly cumulophyric (glomerocrysts ~ 1.0-4.0 mm). Moderately vesicular (vesicles $\leq$ 4.0 mm), intergranular/intersertal, moderately felted.				
265	Medium grey	18 total	0.1-3.0	$\leq$ 0.5	$\leq$ 0.5	0.2-0.6	
Qlp?	Augite intermediate andesite	82 total					
MATRIX COMPOSITION: Plagioclase laths and microlites, small crystals and grains of clinopyroxene, granular magnetite, some small vesicles (commonly in trains).			TEXTURE: Fine to medium grained, marginally seriate, moderately porphyritic, mildly cumulophyric, slightly vesicular. Intergranular/weakly subophitic, slightly pilotaxitic.				

SAMPLE No. / MAP UNIT (MODAL %)	7 / Qcp	134 / Qlp	187 / Qlp	265 / Qlp?
PHENOCRYSTS:				
Plagioclase	18.6	13.1	19.6	14.1
Clinopyroxene	5.9	0.5	1.8	1.4
Orthopyroxene	2.8	0.8	1.2	0.6
Olivine	0.6	0.6	0.9	1.9
Hornblende	0.1	---	---	---
Magnetite	---	---	1.5 (a)	---
TOTAL VOLUME %	28.0	15.0	25.0	18.0
MATRIX:				
Plagioclase	21.4	57.4	26.1	54.2
Clinopyroxene	0.5	14.8	2.8	17.6
Orthopyroxene	---	0.2	0.2	---
Olivine	---	---	---	---
Magnetite	3.4	3.5	5.3	2.1
Hematite	---	---	---	---
Dust, Opaques	9.0	9.1	4.0	7.6
Glass	35.7		28.1	
Void	2.0	---	7.0	0.5
TOTAL VOLUME %	72.0	85.0	75.0	82.0
GRAND TOTAL VOLUME %	100.0	100.0	100.0	100.0
REFRACTIVE INDEX	1.549	1.548	1.546	1.552
SILICA % (Fused Bead)	58.25	58.50	58.75	57.50
ANORTHITE (Microlites)	26-40 (34)	25-42 (33)	19-39 (32)	17-39 (32)
ANORTHITE (Phenocrysts)	33-78	27-81	57-ca. 90	32-78

<u>Flow Rocks</u>. The flow most closely resembling rocks of the conduit facies is represented by sample 187 (Table XI, Fig. 3). Augite is the dominant ferromagnesian phenocryst, but is not as abundant as in sample 7 (Qcp). The pyroxenes are more equant, up to 1.6 mm, but more augite (with minor hypersthene) occurs in the groundmass. Relatively fresh olivine, with thin reaction rims of pyroxene, is slightly more abundant as phenocrysts, and has a better developed crystal habit. Plagioclase phenocrysts ($An_{57-90?}$) have fresh to corroded, wormy states, and some of the larger ones are broken. Prismatic magnetite (1.5 percent) may be pseudomorphic after oxyhornblende. The groundmass contains fairly abundant brown glass, but has a more intergranular-intersertal texture than the flow rock. Plagioclase microlites are composed of intermediate andesine (An_{39}).

Samples 134 and 265 (Table XI, Fig. 3), lower in the section, represent different flows, yet both are characterized by a relatively greater abundance of groundmass augite and less glass than samples 7 and 187. Sample 134 is further distinguished by hypersthene occurring as the slightly more dominant pyroxene phenocryst. Most hypersthene phenocrysts have reaction rims of augite. Some augite phenocrysts, having mild reaction rims of hornblende?, are slightly exceeded in abundance by anhedral olivine with which it is commonly associated in glomerocrysts. Olivine, which forms rare subhedra, is moderately fresh, but has thin reaction halos of pyroxene. Microlithic andesine (An_{42}) is flow aligned, and is subophitically enclosed by tiny subhedral prisms and equant grains of clinopyroxene in the groundmass.

Sample 265 varies from sample 134 in that olivine is the dominant ferromagnesian phenocryst (1.9 percent), exceeding augite by one-half percent. Also, the groundmass augite is less subophitically associated with the plagioclase microlites (An_{39}), but occurs more as evenly-distributed interstitial grains.

There seems to be a general trend for the earlier flows of the Patsy Lake assemblage to have olivine as the main ferromagnesian phenocryst, with augite dominating the groundmass. The younger, darker colored flows, however, appear to more closely resemble the observed petrography of the plug, becoming more glassy and hypersthene-rich with correspondent decreases in olivine and augite.

Intermediate Andesite of The Table Domes

The rocks of The Table domes (Qtd_{1-3}) are among the coarsest in the study area due to both phenocryst content and grain size. They are petrographically homogeneous, and observed mineralogic variations are probably local in scope. The middle Table (Qtd_1) is represented by sample 49, and the younger, approximately coeval south and north

TABLE XII

SELECTED PETROGRAPHIC DATA OF THE TABLE DOMES

SAMPLE UNIT	COLOR ROCK TYPE	PHENOCRYSTS (Vol. %) MATRIX (Vol. %)	PHENOCRYST SIZE (mm) 2V Plag	Cpx	Opx	Ol	Hb
49	Dark grey	32 total	0.1-2.0	≤ 2.0	≤ 2.0	0.3-1.0	0.3-5.0
Qtd1	Hornblende intermediate andesite	68 total					
MATRIX COMPOSITION: Plagioclase laths and microlites, granular pyroxene, fairly abundant interstitial pinkish glass and granular magnetite.		TEXTURE: Fine to coarse grained, hiatal, extremely porphyritic, strongly cumulophyric (glomerocrysts ≤ 11.0 mm). Hyalopilitic/intergranular, felted to locally pilotaxitic.					
110	Dark grey	27 total	0.2-3.0	≤ 0.6	≤ 0.6	≤ 0.6	≤ 2.0
Qtd2	Hornblende intermediate andesite	73 total					
MATRIX COMPOSITION: Plagioclase laths and microlites, minor pyroxene granules, interstitial dust and abundant pinkish glass, some granular magnetite.		TEXTURE: Fine to coarse grained, hiatal, densely porphyritic, strongly cumulophyric (glomerocrysts ≤ 10.0 mm). Hyalopilitic/intergranular. Locally pilotaxitic to felted.					
82	Medium grey	30 total	0,3-2.0	≤ 1.5	≤ 3.0	≤ 1.5	0.2-3.0
Qtd3	Hornblende-augite intermediate andesite	70 total					
MATRIX COMPOSITION: Small plagioclase laths and microlites, minor pyroxene (probably clinopyroxene), interstitial magnetite granules, dust and fairly abundant clear glass.		TEXTURE: Fine to medium grained, mainly hiatal, densely porphyritic, strongly cumulophyric (glomerocrysts ≤ 4.0 mm). Intergranular/intersertal? or mildly hyalopilitic.					
146	Medium greyish brown	40 total	≤ 2.0	≤ 1.0	≤ 1.7	≤ 1.0	≤ 2.0
(Qtd2) xenolith	Hypersthene andesite	48 12 void					
MATRIX COMPOSITION: Small plagioclase laths and crystallites, minor granular pyroxene, fairly abundant brown glass, acicular and prismatic magnetite (after hornblende?), some iddingsite.		TEXTURE: Medium to fine grained, marginally seriate, extremely porphyritic, scoriaceous (vesicles ≤ 2.0 mm). Hyaloophitic.					

SAMPLE No. MAP UNIT (MODAL %)	49 Qtd1	110 Qtd2	82 Qtd3	146 (Qtd2) (a)
PHENOCRYSTS:				
Plagioclase	23.7	18.6	24.4	19.5
Clinopyroxene	2.5	1.5	1.5	3.9
Orthopyroxene	2.0	2.0	1.2	9.8
Olivine	0.3	0.4	0.9	0.7
Hornblende	3.5	4.5	2.1	---
Magnetite	--- (b)	---	---	6.1 (c)
TOTAL VOLUME %	32.0	27.0	30.0	40.0
MATRIX:				
Plagioclase	21.1	9.0	13.6	30.4
Clinopyroxene	0.3	1.4	4.1	---
Orthopyroxene	0.4	0.5	0.2	---
Olivine	---	---	---	0.3 (d)
Magnetite	8.8	5.0	7.5	3.0
Hematite	---	---	---	---
Dust, Opaques	4.0	2.0	6.5	tr.
Glass	33.4	55.1	38.0	14.3
Void	---	---	---	12.0
TOTAL VOLUME %	68.0	73.0	70.0	60.0
GRAND TOTAL VOLUME %	100.0	100.0	100.0	100.0
REFRACTIVE INDEX	1.551	1.542	---	---
SILICA % (Fused Bead)	57.75	59.50	58.00 (e)	---
ANORTHITE (Microlites)	19-36 (34)	20-44 (32)	23-39 (31)	---
ANORTHITE (Phenocrysts)	62-82	26-78	50-81	---

Tables (Qtd_2 and Qtd_3) by samples 110 and 82, respectively (Table XII, Fig. 3).

The rocks of The Table domes texturally resemble those of the Goat Peak Flows, especially Qlg_2, and range in silica content from 57.00 to 59.50 percent. These rocks are classified primarily as hornblende intermediate andesite (Fig. 11). They vary from fine to medium grained, and are hiatal-porphyritic and cumulophyric.

Plagioclase forms euhedral and subhedral phenocrysts up to 3 mm in size, and is zoned An_{21-87}. Plagioclase of the middle Table, however, seems slightly less calcic (An_{78}). Generally, the larger plagioclase phenocrysts show wormy corrosion and embayment, and many contain inclusions of magnetite, pyroxene, oxyhornblende and glass.

Prismatic and subhedral oxyhornblende is the dominant ferromagnesian phenocryst. Individual prisms up to 5 mm long are common, and are pleochroic reddish yellow (α) to brownish yellow (γ). Oxyhornblende, in some rocks, is completely altered to pseudomorphic magnetite, although much is relatively fresh and shows only thin oxidation rims. Comparatively, oxyhornblende is fresher in rocks of The Tables than any observed elsewhere in the study area. However, peripheral corrosion occurs to varying degrees, and primary or secondary rims of hematite are ubiquitous among oxyhornblende crystals associated with the top surfaces of The Tables. Inclusions of oxyhornblende within plagioclase phenocrysts suggests that conversion of hornblende to oxyhornblende took place early in the crystallization phase of these rocks.

Both augite and hypersthene phenocrysts (less than 2.5 mm in size) occur in roughly equal amounts of 1.5 to 2.5 percent by volume, and are commonly juxtaposed as glomerocrysts. Augite ($2V_\gamma = 50^\circ - 55^\circ$ in some rocks of the north Table) forms moderately corroded, subhedral prisms, commonly showing twin seams of $\{100\}$. Pleochroic pinkish (α) to greenish (γ) hypersthene phenocrysts resemble augite in habit, and are commonly fractured and corroded. Small cores of olivine are present in some hypersthene phenocrysts.

Olivine anhedra ($2V \approx 90^\circ$) form sparse (less than 1 percent) phenocrysts up to 1 mm in size. Some is relatively fresh, but most is corroded and typically displays thin marginal halos of pyroxene.

The rocks of The Tables are also among the glassiest in the study area, with pinkish, brownish and colorless glass making up to 55 percent of the groundmass. Glass granules generally have an intersertal to hyalopilitic relationship with other groundmass constituents, comprising tiny andesine microlites (An_{32-44}), granular pyroxene, magnetite and dust. Microlithic plagioclase is commonly flow aligned or appressed, resulting in a pilotaxitic texture. Little or no glass is observed in the oxidized rocks associated with the surfaces.

Rounded and subrounded xenoliths are commonly incorporated in rocks of The Tables (Fig. 26). Two samples, 88x and 144x (Appendix, Fig. 11) have silica values of 55.25 and 61.00 percent, respectively, which differ substantially from the normal silica range of The Tables (Fig. 11). These xenoliths also depart markedly from the host rock in both texture and mineral composition (sample 146; Table XII, Fig. 1).

Sample 146 has subhedral plagioclase phenocrysts (up to 2 mm long) in an open-textured, fine grained groundmass. The larger ones exhibit severe corrosion and glassy inclusions. Prismatic hypersthene, up to 1.7 mm, is the dominant ferromagnesian phenocryst (nearly 10 percent), and exceeds augite by about two and one-half times. Olivine anhedra occur only in small quantities. Acicular magnetite is fairly abundant, and appears to be pseudomorphic after oxyhornblende. The groundmass is moderately glassy (about 14 percent), and has a scoriaceous and slightly diktytaxitic texture. Microlithic plagioclase, magnetite and some iddingsite fulfill the remainder of the groundmass. Sample 146 was not assayed for silica content, but mineralogically, it appears to be dacitic andesite.

Intermediate Andesite of Red Cinder Cone

The scoriaceous cinders of Red Cinder Cone (Qtr) typically exhibit plagioclase phenocrysts up to 2 mm long, and one assay yielded a silica content of 58.75 percent (sample 62; Fig. 11, Appendix). The flows (Qlr_1 and Qlr_2) vary between 57.50 and 58.00 percent silica (Fig. 11), and because augite and hypersthene occur in approximately equal amounts, they are classified as pyroxene intermediate andesite.

Sample 70 (Table XIII, Fig. 3), representing the earlier flow (Qlr_1), like the scoria, has plagioclase phenocrysts zoned An_{47-86}. Plagioclase is euhedral to subhedral, and moderately fresh although some are corroded and have inclusions of magnetite and clinopyroxene. Individual phenocrysts rarely exceed 2 mm, but glomerocrysts attain sizes of 3 mm.

Mildly corroded to fresh augite forms stubby, subhedral prisms with $2V_\gamma = 40^\circ - 45^\circ$, and twin seams of $\{100\}$ are common. Less than half the total augite occurs as phenocrysts in contrast to hypersthene which exists only as phenocrysts. Hypersthene forms euhedral and subhedral prisms up to 1.8 mm long which are mildly corroded and fractured, and characteristically have cores of olivine. Some pyroxenes have thin reaction rims of hornblende? which, in turn, shows variable alteration to magnetite.

TABLE XIII

SELECTED PETROGRAPHIC DATA OF RED CINDER CONE LAVA FLOWS

SAMPLE / UNIT	COLOR / ROCK TYPE	PHENOCRYSTS (Vol. %) / MATRIX (Vol. %)	PHENOCRYST SIZE (mm) / 2V: Plag	Cpx	Opx	Ol	Hb
70	Dark grey	22 total	0.1-2.0	$\leq$ 1.0	$\leq$ 1.8	0.3-1.5	
Qlr1	Pyroxene intermediate andesite	68 10 void		40°-45°			
MATRIX COMPOSITION: Plagioclase laths and microlites with interstitial granular magnetite and clinopyroxene?, fibrous hematite and glass.			TEXTURE: Fine to medium grained, marginally hiatal, densely porphyritic, strongly cumulophyric (glomerocrysts $\leq$ 3.3 mm). Intersertal/intergranular, mildly pilotaxitic, moderately vesicular and diktytaxitic.				
61	Blackish grey	18 total	0.1-2.0	$\leq$ 1.7	$\leq$ 1.2		0.2-0.8
Qlr2	Pyroxene intermediate andesite	67 5 void		40°-45°		~85°	
MATRIX COMPOSITION: Tiny plagioclase microlites, abundant interstitial granular magnetite and fibrous grains and belonites of hematite, some dust and minor olivine.			TEXTURE: Fine to medium grained, hiatal, moderately porphyritic, strongly cumulophyric (glomerocrysts $\leq$ 2.0 mm). Intersertal/intergranular, mildly pilotaxitic, mildly vesicular.				

SAMPLE No. / MAP UNIT (MODAL %)	70 / Qlr1	61 / Qlr2
PHENOCRYSTS:		
Plagioclase	13.2	14.4
Clinopyroxene	1.5 (a)..	1.5 (b)
Orthopyroxene	4.0	1.5
Olivine	2.0	0.1 (c)
Hornblende	0.3	0.5
Magnetite	1.0 (d)..	---
TOTAL VOLUME %	22.0	18.0
MATRIX:		
Plagioclase	21.3	6.7
Clinopyroxene	2.6	---
Orthopyroxene	0.4	---
Olivine	---	tr.
Magnetite	7.1	10.9
Hematite	5.5	4.5
Dust, Opaques	2.0	54.9
Glass	29.1	---
Void	10.0	5.0
TOTAL VOLUME %	78.0	82.0
GRAND TOTAL VOLUME % .	100.0	100.0
REFRACTIVE INDEX	1.552	---
SILICA % (Fused Bead) ...	57.50	58.37 (e)
ANORTHITE (Microlites) ..	27-41 (32)	17-36 (30)
ANORTHITE (Phenocrysts) .	47-86	67

Anhedra and rare subhedra of olivine, up to 1.5 mm, make up 2 percent of the porphyritic element. These phenocrysts are fairly fresh to moderately corroded, and have reaction rims of orthopyroxene. Minor secondary alteration of olivine to iddingsite is also common.

Granular glass makes up about 29 percent of the groundmass, and has a mainly interstitial relationship with slender plagioclase microlites (An_{41}). Microlithic plagioclase tends to be flow aligned, imparting a pilotaxitic texture to the rock. Interstitial granular magnetite, fibrous hematite and augite microlites make up the remainder of the moderately vesicular groundmass.

The younger flow (Qlr_2), represented by sample 61 (Table XIII, Fig. 3), texturally resembles flow Qlr_1 (sample 70), but varies somewhat in composition. Both augite and hypersthene occur in equal amounts as phenocrysts but are notably absent as groundmass constituents. Generally, pyroxene is less abundant than in sample 70, but crystal habit and other pyroxene characteristics are the same. Marginal alteration of the pyroxenes to hornblende, altered, in turn, to magnetite, however, appears more intensive among rocks associated with flow Qlr_2. Replacement is so complete in some rocks that the pyroxenes and some olivine have completely altered to pseudomorphic magnetite. Magnetite is also commonly seen penetrating fractures within the less-impacted crystals. Olivine, as recognizeable phenocrysts, is very rare, but one relatively fresh crystal in sample 61 has $2V_{\gamma} = 85^{\circ}$. The groundmass contains a low 6.7 percent microlithic plagioclase (An_{36}) which, along with the high opaque content (54.9 percent), probably accounts for the dark color of the rock. Unlike sample 70, glass is not present. Intergranular fibrous, red hematite and magnetite belonites comprise the remaining bulk of the groundmass which is mildly vesicular and has a slightly pilotaxitic texture.

Basaltic Andesite of Horseshoe Cone

The tephra of Horseshoe Cone (Qth) varies from 54.50 to 56.25 percent silica, and compares favorably with the 54.50 to 56.75 percent range (Fig. 11) for associated flow rocks (Qlh).

Sample 270 (Table XIV, Fig. 3), a blocky bomb from the cone, is mainly fine grained and composed of subhedral plagioclase phenocrysts up to 2 mm long. The largest ones are intensely corroded. Small olivine subhedra ($2V_{\gamma} = 85^{\circ}$) are the dominant ferromagnesian phenocrysts which, with the silica content, establishes the rock as olivine basaltic andesite.

Olivine is characteristically corroded and embayed, and thin, granular reaction rims of orthopyroxene are common. Local alteration to iddingsite occurs along

TABLE XIV

SELECTED PETROGRAPHIC DATA OF HORSESHOE CONE LAVAS

SAMPLE / UNIT	COLOR / ROCK TYPE	PHENOCRYSTS (Vol. %) / MATRIX (Vol. %)	PHENOCRYST SIZE (mm) / 2V				
			Plag	Cpx	Opx	Ol	Hb
270	Dark grey	12 total	0.3-2.2	0.2-0.5		0.1-0.8	
Qlh	Olivine basaltic andesite	84 4 void		40°		85°	

MATRIX COMPOSITION	TEXTURE
MATRIX COMPOSITION: Plagioclase laths and crystallites, interstitial granular magnetite, minor pyroxene and abundant pink glass.	TEXTURE: Fine to medium grained, hiatal, moderately porphyritic, weakly cumulophyric (glomerocrysts ≤ 2.5 mm), microvesicular. Intersertal/hyaloophitic, mildly pilotaxitic and diktytaxitic?

SAMPLE No. / MAP UNIT (MODAL %)	270 / Qlh
PHENOCRYSTS:	
Plagioclase	7.9
Clinopyroxene	1.0 (a)
Orthopyroxene	---
Olivine	3.1 (b)
Hornblende	---
Magnetite	---
TOTAL VOLUME %	12.0
MATRIX:	
Plagioclase	33.0
Clinopyroxene	0.4
Othopyroxene	0.3
Olivine	---
Magnetite	14.1
Hematite	---
Dust, Opaques	11.2
Glass	25.0
Void	4.0
TOTAL VOLUME %	88.0
GRAND TOTAL VOLUME % .	100.0
REFRACTIVE INDEX	1.560
SILICA % (Fused Bead) ...	56.00
ANORTHITE (Microlites) ..	20-48+ (37) (c)
ANORTHITE (Phenocrysts) .	(d)

fractures and margins, and small inclusions of plagioclase and magnetite are incorporated in some of the phenocrysts.

Remaining phenocrysts comprise 1 percent subhedral prisms of augite up to 0.5 mm, and $2V_{\gamma} \approx 40^{\circ}$. These crystals, like those affiliated with Red Cinder Cone, commonly show twin seams of $\{100\}$.

The groundmass is composed of slender plagioclase laths (about An_{39}) in an intersertal to hyalopilitic relationship with pinkish brown glass (25 percent). Interstitial magnetite and dust, with minor pyroxene form the remaining groundmass constituents. The rock is moderately microvesicular, and plagioclase microlites are arranged in either a felted or flow aligned manner.

Mazama Ash

Whole-rock silica determinations of two ash samples (T.1-H and T.3-10; Fig. 11, Appendix), probably originating from the Mount Mazama eruption, show values of 69.25 and 66.25 percent, respectively. These values, determined via the curve established by Greene (1968) for the Mount Jefferson area, should be considered as approximate. However, determinations derived from the "average curve" of Huber and Rinehart (1966) for volcanic rocks of unknown provenience yielded similar respective silica contents of about 69.50 and 67.00 percent.

Refractive indices of these two samples' glass beads are 1.504 and 1.514 and, though the samples were not pretreated, the values approximate the mean refractive index established for artificial glass of Mazama ash by Randle, Goles and Kittleman (1971). The silica contents compare well with the whole-rock silica determinations of 68.56 percent for Mazama ash near Mount Rainier (Mullineaux, 1974) and 69.70 percent for grey pumice at the Pinnacles near Crater Lake (McBirney, 1968, Table 1).

Basaltic Andesite of Forked Butte

One blackish cinder from Forked Butte (Qtf) (sample 262; Fig. 3, Fig. 11) yielded a silica content of 55.00 percent which is within the 53.75 to 56.50 percent range established for the flow rocks by Greene (1968), McBirney (1968), Sutton (1974) and this study (Fig. 11, Appendix).

The lavas (Qlf_{1-6}) appear homogeneous. They are typically fresh looking, mildly porphyritic, and vary from dense to vesicular. Petrographic descriptions of samples MJW-18, MJW-32 and MJW-95 characterize Qlf_1, Qlf_2 and Qlf_3, respectively (Fig. 3), and are reproduced from Greene (1968) in Table XV.

Along with silica contents, the Forked Butte lavas are classified as augite basaltic andesite due to the dominance of augite as a groundmass constituent. Augite

TABLE XV

SELECTED PETROGRAPHIC DATA OF FORKED BUTTE LAVA FLOWS

SAMPLE / UNIT	COLOR / ROCK TYPE	PHENOCRYSTS (Vol. %) / MATRIX (Vol. %)	PHENOCRYST SIZE (mm) 2V: Plag	Cpx	Opx	Ol	Hb
MJW-18	Color index = 43 Medium dark grey	6.1 total	Phenocrysts 1.0-2.0; 0.1-1.0 mm (two generations)				
Qlf$_1$	Augite basaltic andesite	93.9 (0.02-0.1 mm) (2.3 void)					
MATRIX COMPOSITION: Plagioclase, clino-pyroxene, glass and opaque minerals. NOTE: Sample from Greene, 1968 ("recent andesite").			TEXTURE: Porphyritic, vesicular, granular, flow-aligned. Hiatal.				
MJW-32	Color index = 26 Medium dark grey	9.8 total	Phenocrysts 0.1-2.0 mm				
Qlf$_2$	Augite basaltic andesite	90.2 (0.01-0.5 mm) (19.3 void)	Cpx (Wo:En:Fs) = 41:38:21				
MATRIX COMPOSITION: Plagioclase, clino-pyroxene, glass and opaque minerals. NOTE: Sample from Greene, 1968 ("recent andesite"). Low color index for inferred silica content due to opaque minerals finely divided throughout abundant tachylitic glass.			TEXTURE: Porphyritic, vesicular, Intersertal, flow-aligned. Seriate.				
MJW-95	Color index = 47 Medium dark grey	12.5 total	Phenocrysts 0.2-1.0 mm				
Qlf$_3$	Augite basaltic andesite	87.5 (< 0.01-0.2 mm) (12.7 void)					
MATRIX COMPOSITION: Plagioclase, clino-pyroxene, glass and opaque minerals. NOTE: Sample from Greene, 1968 ("recent andesite").			TEXTURE: Porphyritic, vesicular, intersertal, flow-aligned. Seriate.				

SAMPLE No. / MAP UNIT (MODAL %)	MJW-18 (a) Qlf$_1$	MJW-32 (b) Qlf$_2$	MJW-95 (c) Qlf$_3$
PHENOCRYSTS:			
Plagioclase	4.5	6.3	9.3
Clinopyroxene	0.1	2.2	1.6
Orthopyroxene	---	0.6	0.8
Olivine	1.5	0.7	0.8
Hornblende	---	---	---
Magnetite	---	---	---
TOTAL VOLUME %	6.1 (d)	9.8	12.5 (e)
MATRIX:			
Plagioclase	48.3	27.7	31.5
Clinopyroxene	32.8	9.2	29.8
Orthopyroxene	---	---	---
Olivine	---	---	---
Magnetite	5.8	---	3.7
Hematite	---	---	---
Dust, Opaques	---	0.8 (f)	---
Glass	4.7	33.2	9.8
Void	2.3	19.3	12.7
TOTAL VOLUME %	93.9 (g)	90.2 (h)	87.5 (i)
GRAND TOTAL VOLUME %	100.0	100.0	100.0
REFRACTIVE INDEX	1.574	1.566	1.569
SILICA % (Fused Bead)	53.75 (j)	55.00	54.50 (k)
ANORTHITE (Microlites)	---	---	---
ANORTHITE (Phenocrysts)	56	77	79

also forms the chief ferromagnesian phenocryst, but up to only 2.2 percent by volume in samples MJW-32 and MJW-95. Sample MJW-18 differs by having 1.5 percent olivine as the main ferromagnesian phenocryst, but only by virtue of nearly all augite (32.8 percent) existing within the groundmass. Sample MJW-18 comes from the prominent intracanyon flow (Qlf_1) which trends eastward along the north side of Sugar Pine Ridge, then south, to probably follow Jefferson and Candle Creeks. Comparison between samples MJW-18 and 270 (Qlh), especially with regard to augite and olivine contents, indicates this flow emanated from Forked Butte rather than Horseshoe Cone. Additional, possibly corroborative evidence comes from two chemical analyses: sample 0-181, from a flow on Forked Butte's west side (McBirney, 1968, Table 1); and sample 352, from the intracanyon flow near the confluence of Candle and Cabot Creeks (Hales, 1974, Appendix 5). Although no chemical analyses are available from known flows of Horseshoe Cone, these two analyses are compatible with each other. Other factors thought to favor this interpretation have been mentioned in LITHOSTRATIGRAPHY.

In thin section, the Forked Butte lavas contain moderately sparse plagioclase phenocrysts (An_{56-79}) ranging from 0.1 to 2.0 mm long. Sparse phenocrysts of augite, olivine and hypersthene accompany the plagioclase.

The groundmass is fine grained, vesicular, and contains up to about 33 percent glass (sample MJW-32). Augite subophitically encloses flow aligned plagioclase microlites in some rocks. Textures range from granular to intersertal.

Intermediate Andesite of Hodge Cone

Two bombs from the rim and side of Hodge Cone (Qtc) yielded silica contents of 57.25 and 58.00 percent (Fig. 11, Appendix). Hand specimen examination revealed a minimum 7 to 10 percent phenocrysts comprising euhedral plagioclase up to 2 mm (6 to 9 percent), subhedral pyroxene approaching 1.5 mm (1 to 3 percent), and about one percent, or less, olivine anhedra up to 1.5 mm.

The phenocrysts are set in a dense or vesicular, and apparently glassy groundmass. The rock is tentatively classed as pyroxene intermediate andesite.

GEOLOGIC HISTORY

Introduction

The volcanic rocks in the study area are part of the younger High Cascades, and are probably no more than 1.5 million years old (Taylor, 1968, p. 3). Paleomagnetic sampling of the various units in this study, however, yielded normal (+) polarities, suggesting that most of the volcanic rocks have formed since the last major reversal some 690,000 years ago. The nearest significantly older rocks form Bald Peter shield volcano 9 km to the northeast (Fig. 4), whose rocks are paleomagnetically reversed and yielded an age of 2.1 million years (Hales, 1974, p. 74). Contacts with the basaltic andesite shield volcanoes in the study area and older units to the west are considerably more vague. These shield volcanoes, assigned in this study as "Minto" lavas, have basal portions that may be as old as 4 to 5 million years (McBirney and Sutter, 1975, p. 70), and are seen to unconformably overlie older rocks of the Western Cascades (Peck, and others, 1964; Taylor, 1968, p. 3).

Pre-Abbott Butte Glaciation

The bulk of the High Cascades platform probably developed prior to Abbott Butte glaciation (Scott, 1977, p. 121). Minto lavas composed predominantly of basaltic andesite erupted from numerous vents, forming broad, coalescing shield volcanoes whose flows had generally shallow dips and relatively uniform thicknesses. Within the study area, these shield volcanoes are represented by: 1. the older, coeval "Hunts Cove" (Qv_1) and "Cathedral Rocks" assemblages, and volcanic rocks underlying North Cinder Peak (Qv_2); and 2. the slightly younger, coeval Bear Butte (Qlf) and Sugar Pine shield volcanoes (Qls). Lavas from both Bear Butte and Sugar Pine volcanoes likely onlapped older Bald Peter lavas to the east. Near the Cascades crest these volcanoes now remain as highly eroded ridge crests, sculpted by repeated later glaciations.

Comparatively small tephra cones and composite volcanoes commonly developed near the shield volcano summits during more explosive terminal phases, but fragmental deposits were relatively negligible. Bear Butte (Qnb) and parts of the Sugar Pine Ridge summit area (Qns) are examples.

According to Scott (1977, p. 121), highly dissected, major composite volcanoes such as Mount Washington and Three-Fingered Jack to the south may also pre-date Abbott

Butte glaciation. In addition, Scott (1977, p. 121) implies the early portion of the main cone of Mount Jefferson may have formed at this time, but Sutton (1974, p. 103) claims that no glaciation occurred during main cone development.

Abbott Butte Glaciation

The Abbott Butte glaciation is the earliest recognized in the Metolius River region, and although its extent is uncertain, it probably attained localized ice-cap proportions generally more extensive than later glaciations (Scott, 1974, Table 4; 1977, p. 122-123). This glaciation likely had a dominant planing effect on the landscape prior to valley deepening caused by subsequent glaciations. Evidence of older drifts has not been observed, but it is possible that they exist. Evidence of the Abbott Butte glaciation within the present study area relies on differential erosion and stratigraphic relationships of the volcanic units. Virtually all the Minto lavas were subjected to glacial erosion at this time as far as Bald Peter, 9 km to the northeast of the study area.

Abbott Butte/Jack Creek Interglaciation

The volcanic rocks produced during the Abbott Butte/Jack Creek interglaciation have been named the Brush Creek formation by Scott (1977). North Cinder Peak shield volcano and probably the bulk of the Main Cone of Mount Jefferson formed during this period. The original size of the North Cinder Peak is uncertain, but lavas of andesite and basaltic andesite (Qln) flowed at least 2 km quaquaversally from the vent, onlapping Minto lavas. One thick intracanyon flow travelled about 8 km down the glacial valley now occupied by Cabot Creek (Scott, 1974, p. 50), perhaps unconformably overlying the older lavas of Sugar Pine volcano (Figs. 1; 2, section A-A'). Evidently during a more explosive later phase, North Cinder Peak developed a small composite cone (Qnn) near the summit.

The Goat Peak assemblage also formed at this time. First, a minimum of four thick andesitic lavas, the Table Lake sequence (Qta_{1-4}), flowed southeast from a vent at or near Goat Peak, around the eroded southwest corner of Bear Butte, then eastward down the valley between Bear Butte and Sugar Pine volcanoes. The second phase consisted of probably more explosive volcanism accompanied by two short successive flows of hornblende dacite from Goat Peak (Qlg_1, Qlg_2), overlying the earlier Table Lake lavas. Goat Peak (Qcg) itself constitutes a plug or plug dome of hornblende dacite.

About the same time the Table Lake lavas erupted, a 120 m-thick flow of dacitic andesite (Qil) filled a glaciated valley abutting the Cathedral Rocks and Hunts

Cove lavas, and early Mount Jefferson Main Cone lavas. This flow trended northwest, sloping about 7 degrees in that direction. Its headward portion was subsequently truncated by glacial erosion, so its source is unknown. Conjecturally, the source area was a now-eroded highland in the area presently occupied by the Tables.

Jack Creek Glaciation

During Jack Creek glaciation, ice covered about 305 km^2 in the Metolius River area, forming a thin but continuous sheet eastward from the crest, down to elevations of about 1000 to 1300 m (Scott, 1974, p. 60; 1977, p. 115, 122). Both till and outwash facies abut Green Ridge near the Metolius River, 14.5 km to the east, and a like amount was deposited to the west as well.

The ice again flowed over the previously glaciated plateau of Minto volcanoes, planing them, broadening valleys and deepening their headward portions. Large cirques were likely excavated at this time, including Hunts Cove and the one occupied by the Tables. In addition, most of the northeastern half of North Cinder Peak and large parts of Bear Butte and Sugar Pine volcanoes were stripped away.

Jack Creek/Cabot Creek Interglacial

Scott (1977) assigned the name, South Cinder Peak formation to volcanic rocks produced during the Jack Creek/

Cabot Creek interglacial. Except for some residual ice on the higher volcanoes and some less-extensive advances, the glaciers largely disappeared from the High Cascades during this time.

The Main Cone of Mount Jefferson (Qmj) probably attained its greatest height prior to Jack Creek glaciation. After the cone had undergone glacial erosion, fissure eruptions locally covered the volcano with thick dacitic andesite flows (Qsj). These were termed the "Second Stage" lavas by Sutton (1974), and can be seen overlying Jack Creek till which in turn overlies eroded Main Cone lavas near the head of Russell Glacier. Some of these lavas erupted from the south flank of Mount Jefferson and flowed south and southwest where they terminated 1 km north of Shale Lake. The latter arm is covered with younger tephra and admixed glacial deposits, so its extent is uncertain.

About the same time as the Mount Jefferson Second Stage event, "Patsy Lake" volcano formed near the mouth of the "Table" cirque, sending a series of 1 to 2 m-thick andesite flows (Qlp) a minimum of 3.5 km eastward down Jefferson Lake valley. To the north, they flowed over the earlier scoured Table Lake lavas, and against older North Cinder Peak and Minto lavas to the south.

Following these two events, the Tables (Qtd_{1-3}) formed within the cirque between Goat Peak and the Patsy

Lake volcano, erupting along an inferred north-south fissure as domes transitional to stiff lava flows. The Tables also abutted and probably flowed over rocks of Goat Peak to the east. To the west, the Tables unconformably overlie the Cathedral Rocks, Mount Jefferson lavas and probably portions of the beheaded intracanyon flow (Qil).

The middle Table (Qtd_1) erupted first as a roughly circular body, and was partially overridden by the later south and north Tables (Qtd_2, Qtd_3). The vent of the north Table probably formed on the cirque head, and consequently flowed southward until being obstructed by the middle Table. The south Table also impinged upon the middle Table as well as covering part of the Patsy Lake lavas (and perhaps a portion of the central facies). The configurations of the Tables are due, in part, to their restricted environment within the cirque, yet where the south Table had an avenue of escape on its southeast side, it flowed only a minimal distance in that direction.

Cabot Creek Glaciation (Suttle Lake Advance)

The Cabot Creek glaciation comprised the Suttle Lake advance and the later, two-phase Canyon Creek advance. According to Scott (1974, p. 63), the Suttle Lake advance covered about 225 km^2 within the Metolius River area, and stood as thick as 750 m near the valley heads east of the Cascades crest. Although the ice accumulated on the volcanic plateau, it tended to follow the valleys which had been previously deepened by Jack Creek glaciation. Within these valleys, Suttle Lake ice extended, for the most part, as far as Jack Creek ice had previously.

It was during this glaciation that the Cascades platform essentially acquired its present aspect. It was mainly a time of scouring and streamlining rather than planing. Lateral moraines from this glaciation border Jefferson Creek valley, flanking the southern tip of Bald Peter to the east, and the north and east sides of Sugar Pine Ridge. Ground moraine from Cabot Creek glaciation blankets much of the study area. Locally, only the summit portions of Bear Butte and Sugar Pine volcanoes stood above the ice as nunataks (Scott, 1974, p. 63-64). The Tables and Patsy Lake volcano were scoured by at least 150 m of Suttle Lake ice which, in this locality, had a pronounced southeasterly flow direction (Fig. 1). Anything in the nature of a brecciated carapace on the Tables was evidently removed at this time.

Volcanism between the Suttle Lake and Canyon Creek Advances

The only volcanic activity between the retreat of Suttle Lake ice and the Canyon Creek advance was the eruption of Red Cinder Cone. This tephra cone (Qtr), situated on the south flank of Mount Jefferson, produced two andesitic lava flows (Qlr_1, Qlr_2) and an adjacent scoriaceous tephra blanket (Qtbr). The tephra covered the flanks of Goat Peak and the headward part of the north Table. The lavas flowed eastward down upper Jefferson Lake valley, paralleling the eroded north side of Bear Butte, a distance of perhaps 6.5 km. Scott (1977, p. 115) includes Red Cinder Cone with the South Cinder Peak formation.

Cabot Creek Glaciation (Canyon Creek Advance)

The Canyon Creek advance of Cabot Creek glaciation consisted of two phases, and together (exclusive of Mount Jefferson), covered 48 km^2 - roughly 20 percent of the extent of the Suttle Lake advance. Of this, about 93 percent of the ice cover occurred during phase 1 (Scott, 1974, p. 60; 1977, p. 115).

During phase 1, localized glaciers occupied cirques along the Cascades crest and on the larger volcanoes. The moraines seen on top of the Tables probably formed during this advance. Red Cinder Cone was also affected by this ice, but evidently not over-ridden by it.

Most of the phase 2 glaciers were small, and restricted to north and northeast-oriented cirques and protected areas like the trough west of the Tables. Many of these glaciers became covered with rock debris, eventually forming protalus ramparts, rock glaciers and ablation deposits.

Holocene Volcanism

The beginning of Holocene time is marked by a 15 to 40 cm-thick unit of fine, yellowish orange tephra (unmapped) from the climactic Mount Mazama eruption, 6600 years ago. This ash blankets most of the study area. Shortly thereafter, three tephra cones of andesite and basaltic andesite erupted locally. These volcanoes, Forked Butte, Horseshoe Cone and "Hodge" Cone, were all ascribed to the Forked Butte formation by Scott (1977). All these volcanoes are unglaciated and have fresh appearances.

Forked Butte (Qtf) erupted approximately 6400 to 6500 years ago (Scott, 1977, p. 122) along a fissure which cut the cirque headwall between North Cinder Peak and Sugar Pine Ridge. Flows of basaltic andesite (Qlf_1) initially travelled around the north side of Sugar Pine Ridge almost to the Metolius River, a distance of 15 km. Later lavas (Qlf_2) breached the south side of the cone. They cascaded over the intracanyon flow of North Cinder Peak (south of the study area), and flowed 9.5 km down Cabot Creek valley, to its mouth, where it terminated against the earlier flow (Qlf_1). In addition, a tephra deposit (Qtfb), indicating two eruptive phases, blanketed most of the immediate surroundings up to 2 m deep. This unit of ash and scoriaceous lapilli conformably overlies the Mazama ash.

About the same time as the eruption of Forked Butte, and perhaps slightly earlier, Horseshoe Cone (Qth) erupted in line with the dikes of Bear Butte and Sugar Pine Ridges. This cone of ash and scoriaceous lapilli produced flows (Qlh) similar to those of Forked Butte which dammed Jefferson Lake, covered portions of the Table Lake lavas, and flowed an indeterminant distance down Jefferson Lake valley.

The youngest volcanic event in the study area is Hodge Cone (Qtc), located on the south side of the south Table. This small, pristine tephra cone partially overlapped the eroded Patsy Lake plug and part of the south flank of the south Table. It produced a small summit crater but no flows.

Neoglaciation

During the last few centuries, glaciers attained their Holocene maxima. Scott (1977) named this the Jefferson Park advance, for which he identified two phases. During this advance, glaciers were restricted to sheltered cirques and valleys on the large composite volcanoes (Figs. 1, 29). Phase 1 glaciers within the Metolius River area covered about 10 km^2, and phase 2 glaciers, half that much (Scott, 1974, Table 5). As Scott observes, phase 2 terminal moraines (Qjt_2) lie close to present day glacial termini, and within 1.5 km of phase 1 terminal moraines (Qjt_1). Phase 1 outwash and till deposits occur in the northern map area, where they encroach earlier Jack Creek till and the north side of Red Cinder Cone. All the neoglacial deposits overlie Mazama ash.

Presently, within the study area, volcanic processes are inactive, and glacial activity is waning. The dominant processes today comprise locally intense colluviation and mild periglacial activity.

DISCUSSION AND CONCLUSIONS

The wide variety of Quaternary volcanoes and rock types occurring in the study area, coupled with multiple Pleistocene glaciations, may be considered representative of the complex manner in which the High Cascades have evolved. In addition, the stratigraphic relationships between the resultant drift deposits and volcanic rocks serve as a useful relative dating frame for the eruptive events.

Rock types were successfully classified on the basis of silica content as the primary independant variable. Silica contents were determined by fusion analysis (refractive index measurements) of whole-rock glass beads and employment of the curve established by Greene (1968, p. G8) for rocks of the Mount Jefferson area. Secondary rock classification relied on modal mineralogy with respect to silica content.

Of the 217 rocks selected as a silica content base (including the 126 values determined in this study), approximately 80 percent fell between 54 and 62 percent silica which is compatible with the predicted unimodal frequency distribution projected by Greene (1968, p. G12) for a systematic series of rock samples from the Mount

Jefferson area. Collectively, they cluster somewhat below the average of 58.17 percent determined by Chayes (1969) for Cenozoic andesites. Basalt (<53 percent silica), and the more silicic andesites and dacites are proportionately less abundant. The rocks of the High Cascades near Mount Jefferson have an alkali-lime index of about 61 (Greene, 1968, p. G35), making them transitional between the calc-alkalic and calcic suites defined by Peacock (1931). As a whole, the rocks of the High Cascades cluster in the lower portions of the calcic suite.

The oldest rocks within the study area are associated with broad, coalescing shield volcanoes composed of microporphyritic, olivine and augite basaltic andesite. These are assigned to the Minto lavas which, to the west, onlap the more distal and older volcanoes of the Western Cascades. Within the mapped area, the Minto volcanoes generally become younger and higher in the section towards the east, but all probably interfinger to a degree. In keeping with the model of Cascade volcano evolution presented by Williams (1944), many of these shields developed small (by comparison) composite volcanoes on or near their summits during relatively more explosive later phases. Sugar Pine, Bear Butte and North Cinder Peak volcanoes show this relationship to varying degrees.

The large composite volcano of Mount Jefferson itself may be superposed over one of these large shields.

The Minto lavas erupted prior to the first (Abbott Butte) glaciation (Scott, 1977). Both this and the second (Jack Creek) glaciation had a predominant planing effect on the landscape, and with each successive advance, valleys were progressively broadened and deepened headward. The final (Cabot Creek) glaciation tended to scour and streamline more than plane with the consequence that the older volcanoes now stand as elongate, commonly castelated ridges. As a result, younger flows formed increasingly distinct intracanyon relationships with the older rocks.

Following the stage of High Cascades evolution entailing construction of basaltic andesite shield volcanoes, and up to Holocene time, volcanism steadily became more localized and generally more silicic. As Greene (1968, p. G46) observed, however, most Holocene volcanoes within the Mount Jefferson area acquired silica contents more like those of the older (Minto) lavas, and may "represent a reappearance of undifferentiated parental magma in new vents along the same line of crustal weakness occupied by the major vents of the High Cascades." This trend appears to be upheld in the volcanic rocks in the study area, but is manifested more as an apparent gradual increase in silica culminating with the Goat Peak dacite eruption (Fig. 32). Following this event, a gradual reverse trend is indicated back towards more mafic compositions. The validity of this trend and its full implications, however, must await chemical analyses of the rocks, particularly in regard to the conclusions drawn by Sutton (1974) that "the different groups of lavas were probably separate partial melts of the mantle or lower crust," not genetically connected directly.

The volcanoes in the study area also become more diverse in form, mineralogy and mode of eruption through time. This diversity is shown in part by: the large composite, two-stage cone of Mount Jefferson; tephra cones such as Forked Butte which produced aa flows of olivine and augite basaltic andesite up to 14 km long; the short, blocky hornblende dacite flows of Goat Peak, itself a plug dome perhaps of the Peléean type; and the coarse-grained, quasi-domal, hornblende intermediate andesite of The Table.

Bear Butte and Sugar Pine shield volcanoes lie a few kilometers east of the main High Cascades axis. The different facies of these volcanoes are cut by several northwest-trending dikes whose orientations were probably governed by tectonic rather than volcanic processes. Another indication that these intrusions reflect an underlying zone of recurrent crustal weakness along which magma could ascend is the presence of Horseshoe Cone along

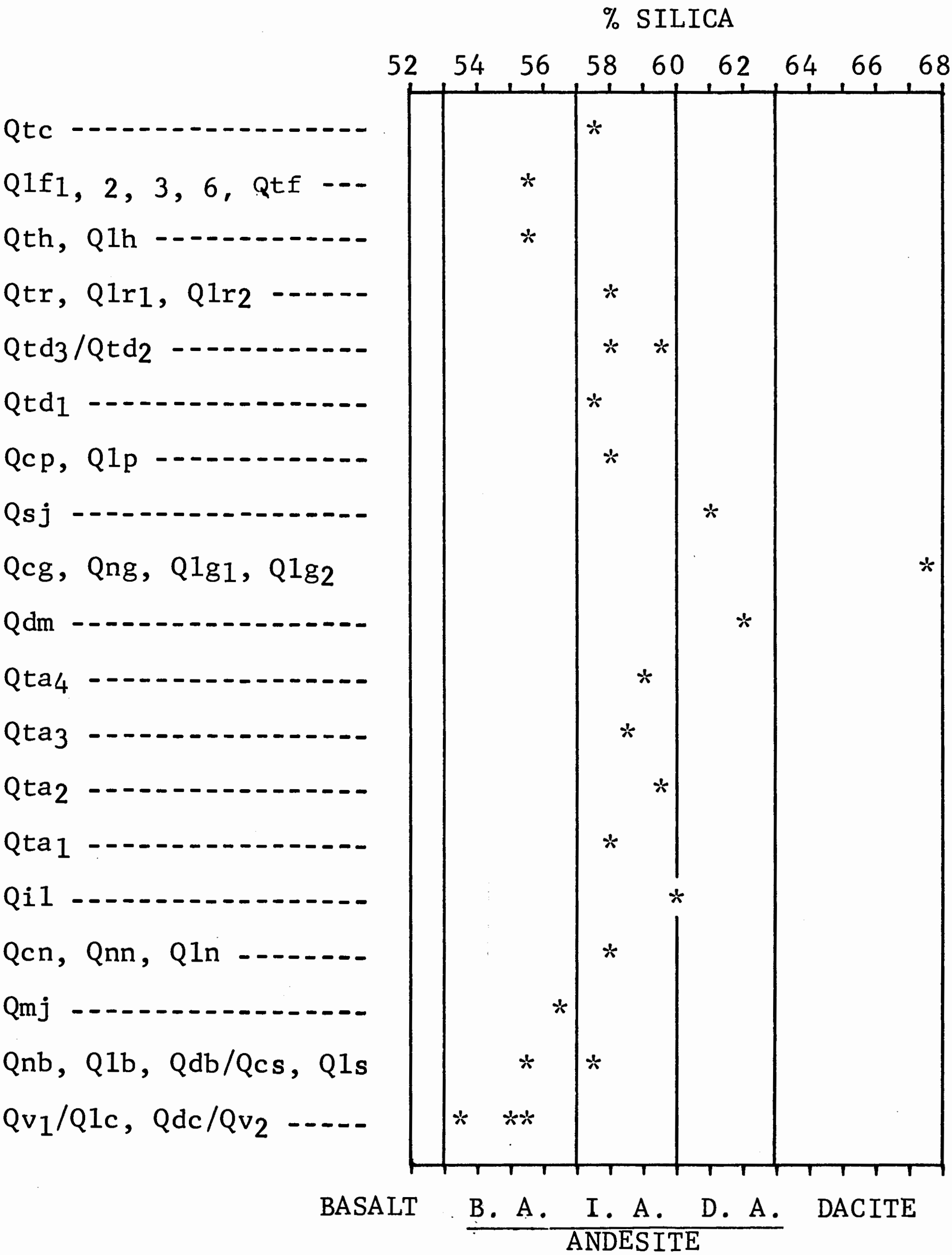


Figure 32. Chronologically ordered average silica distribution in the volcanic units.

the same trend. No flows were seen to emanate from the dikes cutting Bear Butte and Sugar Pine Ridge, but their upper portions have been eroded by glaciation, obliterating any evidence of late-stage fissure flows, perhaps like those forming the Mount Jefferson Second Stage lavas.

This apparent fracture zone is in line with or parallels other known northwest-trending lineaments such as the "Northwest Rift Zone" (Nichols and Stearns, 1966), the Black Butte faults (Peterson and Groh, 1972) and the "Tumalo Fault"-Bald Peter fault (Hales, 1974) (Fig. 4). This system is apparently a northwestward extension of the conspicuous N55°W - trending "Brothers Fault Zone" (Higgins and Waters, 1967; Allen and Beaulieu, 1976), intersecting the High Cascades lineament in the vicinity of Mount Jefferson and the study area (Fig. 4).

The phenomenon of large volcanic edifices and complexes forming along or at the intersection of linear zones of crustal weakness has been documented. Newberry Caldera, for example, lies near where the Brothers Fault Zone intersects the Cascades lineament and the Walker Rim lineament (Allen, 1965, p. 22; Higgins and Waters, 1967). Similar relationships are noted for Crater Lake, Valle Grande Caldera, New Mexico, and the Rhine Graben in Germany (Allen, 1965; Macdonald, 1972, Fig. 14-9). The large composite cone of Mount Jefferson and possibly the inordinately abundant degree of volcanism in the study area may also exist as a response to these relationships. That part of this fault system may form the eastern boundary of a regional north-south graben bordering the High Cascades constitutes a long-standing topic of debate. Such a feature has been inferred by Allen (1965) and Hales (1974), and referred to as a volcano-tectonic depression by extrapolation from localized faulting, stratigraphy, and reliance on the aforementioned models. The volcano-tectonic model appears to hold to the east of the study area where rocks, evidently correlative with the Western Cascades, have been down-dropped to the west by a series of parallel, north-south faults (Fig. 4; Hales, 1974). In contrast to the eastern side, however, there is still controversy as to the nature of the regional western contact. Localized, north-south trending faults do occur, such as those associated with the Hood River Graben (Allen, 1965), but there is no firm evidence of major north-south regional faulting west of the study area. Taylor (1968, p. 3) observes that if any such fault or fault system exists, it is not exposed, and the faults that do occur are short, trend northwest, and are tied to the Western Cascades. Depending on structural configurations, however, it is possible that any original fault contact(s) between the Western and High Cascades has long-since been obscured by prograding lavas from the coalescing shield volcanoes. As Hammond (1976, p. 82-83) observes, the contact is presently manifested as a sinuous but regionally straight line of volcanic deposition and erosion.

To the east, along the Cascades crest, the north-south alignments are better demonstrated. The Table is one such example. The Table is a flat-topped volcanic feature, consisting of three discrete oval members, occupying a cirque carved during Jack Creek glaciation. Other attributes of the Tables comprise: 1. surficial, arcuate lineations with concentric patterns; 2. peripherally distributed, steeply dipping flow planes; 3. oxidized surface rocks; 4. localized divergent 'fanning' of flow units; 5. abrupt, steep sides, and; 6. limited lateral flowage. Furthermore, the Tables are contiguously aligned in a north-south direction, along the High Cascades axis, indicating an underlying fissure.

Although the Tables formed individually, they may be considered as a single volcanic event. The middle Table formed first, and probably was nearly circular in its original form. It was later partially over-ridden by the younger, nearly coeval north and south Tables. The Tables were subsequently scoured by the Suttle Lake advance of Cabot Creek glaciation (Scott, 1977), eroding most of any surficial materials such as surface or crumble breccias, and leaving behind deposits of ground moraine.

The Tables probably grew through endogenous expansion in much the same manner as Big Obsidian Flow and Rock Mesa in the central High Cascades (Williams, 1935; Peterson and Groh, 1966, p. 1, 4, 7, 17), Southern Coulee in the Mono Craters area, California (Loney, 1968, p. 421) and the Tarawera domes of New Zealand (Cole, 1965). The arcuate lineations on the tops of the Tables are evidently surficial expressions of diverging nested flow planes or wave fronts commonly formed within viscous lava flows and domes such as cited above. Specifically, the south Table appears to have moved outward through several surges and perhaps different rates, but generally to the southeast. This preferred flow direction seems to have been controlled by a channel formed by the middle Table and the underlying/ earlier Patsy Lake lavas (Figs. 1; 2, section H-H'). Locally, where the lava became excessively viscous, the distal portions ramped upwards in a manner characteristic of blocky lava flows. These areas were then presumably thrust upwards by successive internal surges. The arcuate lineations observed on top the Tables are interpreted as reflecting this phenomenon.

Another indication that the Tables grew, at least in part, by endogenous expansion is shown by zones of flow layering (foliation) locally exposed around the peripheries, probably reflecting the same mechanism responsible for the arcuate surface lineations.

The north Table developed a more conventional blocky flow style due to its formation on the cirque headwall, resulting in a downslope flow vector in a manner resembling some of the Merapi domes of Java (Bemmelen, 1949). The northern extent of the north Table is uncertain, but the headward exposure may well be in proximity to the vent as indicated by the chaotic flow structure seen on the northeast side. The downslope concentric nesting of flow units of the north Table (Fig. 28) may be mainly in response to obstructions encountered on all sides during lava flowage.

The shapes of the south and middle Tables were determined in part by their impeding effect on each other and, to some degree, to their confinement within the cirque. It remains problematic, however, as to why the Tables appear to fill only the space within the cirque. The flat tops attest to some element of attained hydrostatic equilibrium, and even where an avenue of escape existed (e.g., the southeast side of the south Table), lateral flowage was minimal. There is no evidence that the middle Table flowed laterally to any extent. In light of the flat tops, abrupt sides and surface structure, then, it appears the Tables (the south and middle Tables in particular) essentially formed as domes which, to varying degrees, terminated as stiff, blocky lava flows. Due to erosion, the locations of the tholoids are revealed or inferred by exposed flow structure in the sides of the Tables and by projection from the concentric, arcuate surface patterns. Development of three such features rather than a single 'large' one may be attributed to lavas of the north and south Tables, given a limited supply of magma, to more readily erupt from distal parts of the inferred fissure than for lava to force itself into the middle Table beyond some critical point of hydrostatic equilibrium and viscosity.

The problem remains of accounting for those factors responsible for the apparent high viscosity of the Tables and, therefore, their domal attributes. Even though the rocks contain up to 6 percent hornblende (as oxyhornblende), the Tables have an average silica content of only 58 percent (intermediate andesite) which, in itself, does not appear rich enough to fully account for the viscous nature of the Table lavas. Other factors must, therefore, be involved.

The main variables controlling the viscosity of lavas are fairly well known but their relationships are complex, and it is often difficult to isolate the specific ones leading to dome development. As Macdonald (1972, p. 97-98) indicated, the differences between domal lavas and stiff lava flows are largely gradational. Rock compositions of domes vary from basaltic to rhyolitic (Williams, 1932, p. 136-137), so chemistry (specifically silica) is not the only controlling factor even though a direct relationship exists between silica content and lava viscosity. The converse, however, is not necessarily true. With decreasing silica, physical variables such as low temperatures and low dissolved volatile content become more critical than chemical factors with regard to viscosity of lavas, and probably the development of domes (Williams, 1932, p. 136-137, 139). These physical factors in conjunction with a limited supply of lava are, likewise, those probably most contributory in the formation of the Tables.

The high glass content in the groundmass portion of the rocks of the Tables (up to 55 percent) indicates the features de-gassed and chilled rapidly. Whether this was due to an inherent property of the lava, or due to external factors, is presently unknown. However, the process was apparently rapid enough to impede ion migration, thereby precluding development of a more thoroughly crystallized groundmass. It is noteworthy that little or no glass is present in the oxidized rocks on the surfaces and along the flow planes of the Tables. This may be an effect of localized post- or syn-eruptive increases in temperature and circulating volatiles in areas of escaping gas. Much of this volatile activity probably concentrated along ascending flow planes which, in conjunction with zones of fumarolic activity, served to convey underlying volatiles (including ground water) to the surface. Under such conditions glass is removed from its stability field and devitrified (Williams, and others, 1954, p. 15). Also in these areas of oxidation, most of the iron-bearing constituents of the rocks, particularly oxyhornblende, have altered to hematite in varying degrees, expecially within the groundmass.

The complex cooling history of the Tables is reflected by several joint styles of which the cordwood-hackly jointed rock is perhaps the most puzzling. The long axes of the short cloumns are commonly oriented normal to the slope of the Tables, and may be a surficial expression of lava lobes contacting cooling fronts such as a crumble breccia. More speculatively, this joint style may also have formed in a manner such as described by Mathews (1951b) for The Table (British Columbia) where lava poured downslope into narrow spaces between the volcano and a surrounding ice sheet. However, although the Tables (this study) were glacially scoured by Cabot Creek ice after their formation, no direct evidence was found to indicate that they formed within or adjacent to any large ice body. As Scott (1977, p. 122) notes:

> ...during most of Pleistocene time ice cover was probably limited (in the study area...), and the probability of an eruption coming into contact

> with ice was small. It is also possible that intraglacial volcanism did occur, however, but evidence for it has either been incorrectly interpreted or eroded or buried during subsequent ice advances or volcanic erputions.

It is also a possibility that the cordwood jointing, which has highly localized distribution, is simply an intrinsic characteristic of the compact, interiors of the Tables, reflecting their differential cooling rates. The pillow-like lava nodules observed in the north Table constitute the only tangible evidence for partial eruption into or contact with a moisture-laden environment.

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APPENDIX

SILICA DETERMINATIONS BASED ON REFRACTIVE INDICES OF FUSED BEADS

SAMPLE NUMBER*		REFRACTIVE INDEX		SILICA PERCENT	MAP UNIT	NOTES
63		1.500		70.75	Qng	
69		1.502		70.00	Qlg_1	
40	---	1.503	---	69.75	Qng	
T.1-H		1.504		69.25	--	Mazama? ash, below Qtfb.
81		1.505		69.00	Qlg_1	
207*	---	1.508	---	68.00	Qlg_1	
42*		1.508		68.00	Qcg	
255		1.508		68.00	Qlg_1	
251	---	1.512	---	67.00	Qlg_1	
T.3-10		1.514		66.25	--	Mazama? ash, below Qtfb.
156		1.515		66.00	Qv_2	Dacite crystal-lithic tuff?
71	---	1.520	---	64.50	Qlg_2	
210*		1.520		64.50	Qlg_2	
223		1.525		63.25	Qlg_2	
65	---	1.526	---	63.00	Qdm	
44		1.533		61.50	Qdm	
MJW-105		1.534		61.00	Qsj	Greene, 1968; off map.
144x	---	1.535	---	61.00	(Qtd_2)	Xenolith of south Table.
274		1.535		61.00	Qil?	
243		1.539		60.00	Qta_2	
]38	---	1.539	---	60.00	Qta_2	
107		1.540		60.00	Qta_2	
267		1.540		60.00	Qta_2	
216	---	1.540	---	60.00	Qil	
139*		1.541		59.75	Qta_2	
67*		1.541		59.75	Qil	
202	---	1.542	---	59.50	Qta_4	
101		1.542		59.50	Qta_2	
34		1.542		59.50	Qtd_2	
110*	---	1.542	---	59.50	Qtd_2	
48		1.542		59.50	Qtd_3	
180		1.543		59.25	Qln?	
201	---	1.543	---	59.25	Qta_4	
144		1.544		59.25	Qtd_2	
229		1.544		59.25	Qta_4	
249	---	1.544	---	59.25	Qta_4	
11*		1.544		59.25	Qta_4	
88		1.545		59.00	Qtd_2	
247	---	1.545	---	59.00	Qta_4	
246		1.546		58.75	Qta_4	
62		1.546		58.75	Qtr	Scoriaceous lapilli.
187*	---	1.546	---	58.75	Qlp	
225		1.546		58.75	Qta_4	

APPENDIX (con't.)

SAMPLE NUMBER		REFRACTIVE INDEX		SILICA PERCENT	MAP UNIT	NOTES
189		1.546		58.75	Qlp	
245		1.547		58.50	Qta3	
77	---	1.547	---	58.50	Qtd3	
204		1.548		58.50	Qta3	
25		1.548		58.50	Qtd2	
134*	---	1.548	---	58.50	Qlp	
7*		1.549		58.25	Qcp	
248		1.549		58.25	Qta4	
196	---	1.549	---	58.25	Qta3	
199		1.549		58.25	Qta3	
64		1.549		58.25	Qmj	
103	---	1.549	---	58.25	Qlp	
113		1.549		58.25	Qtd2	
258*		1.549		58.25	Qcs	
192	---	1.550	---	58.00	Qta2	
238		1.550		58.00	Qlp	
272		1.550		58.00	Qls?	
239*	---	1.550	---	58.00	Qta1	
87		1.550		58.00	Qlr2	
126		1.550		58.00	Qlp	
244	---	1.550	---	58.00	Qta2	
177		1.550		58.00	Qcn	
89		1.550		58.00	Qtc	Scoriaceous bomb.
185	---	1.551	---	57.75	Qlp	
49*		1.551		57.75	Qtd1	
172*		1.551		57.75	Qnn	Lava flow.
182	---	1.552	---	57.50	Qln?	
70*		1.552		57.50	Qlr1	
265*		1.552		57.50	Qlp/Qls?	
8	---	1.552	---	57.50	Qln	
171		1.552		57.70	Qln	
179		1.552		57.50	Qln?	Small outcrop.
153	---	1.552	---	57.50	Qv2	Dike.
170		1.553		57.50	Qln	
166		1.553		57.50	Qln	
58	---	1.554	---	57.25	Qtd3	
220		1.554		57.25	Qtd1	
90		1.554		57.25	Qlp?	In crater of cone.
133	---	1.554	---	57.25	Qtc	Bomb from rim of cone.
190		1.554		57.25	Qlp	
73		1.555		57.00	Qtd3	
33	---	1.555	---	57.00	Qtd3	
80		1.555		57.00	Qta3?	
117		1.555		57.00	Qlp?	
257	---	1.556	---	56.75	Qcs	
230		1.557		56.75	Qlh	

APPENDIX (cont'd.)

SAMPLE NUMBER	REFRACTIVE INDEX	SILICA PERCENT	MAP UNIT	NOTES
181	1.558	56.50	Qlf_3	
47	1.558	56.50	Qmj	
66 ---	1.558 ---	56.50	Qmj?	
227	1.559	56.25	Qth	Scoriaceous lapilli.
277*	1.559	56.25	Qlc/Qv_1	
MJW-96---	1.559 ---	56.25	Qcn	Greene, 1968. Refined value.
237*	1.560	56.00	Qlb	
263	1.560	56.00	Qlf_1	
231* ---	1.560 ---	56.00	Qdb	
259	1.560	56.00	Qlf_1	
123	1.560	56.00	Qlf_6	
270* ---	1.560 ---	56.00	Qlh	
261	1.561	56.00	Qlf_1	
278	1.561	56.00	Qv_1	Dike.
214 ---	1.563 ---	55.75	Qlc	
152	1.564	55.50	Qv_2	Dike.
235	1.564	55.50	Qlb	
120 ---	1.564 ---	55.50	Qlf_3	
129	1.564	55.50	Qlc	
236	1.564	55.50	Qdb	
74-12D---	1.565 ---	55.25	Qth	Grey scoriaceous lapilli.
88x	1.565	55.25	(Qtd_2)	Xenolith of south Table.
23	1.566	55.00	Qlc	
91 ---	1.566 ---	55.00	Qdc	
96	1.566	55.00	Qlc	
218	1.566	55.00	Qlc	
21 ---	1.566 ---	55.00	Qlc	
MJW-32	1.566	55.00	Qlf_2	Greene, 1968.
275*	1.567	55.00	Qlc?	
215 ---	1.567 ---	55.00	Qlc	
131	1.567	55.00	Qlc	
262	1.567	55.00	Qtf	Scoriaceous lapilli.
228 ---	1.567 ---	55.00	Qth	Scoriaceous lapilli.
151	1.567	55.00	Qv_2	
130	1.568	54.75	Qlc	
234 ---	1.568 ---	54.75	Qlb	
MJW-95	1.569	54.50	Qlf_3	Greene, 1968. Refined value.
233	1.569	54.50	Qnb	
74-12L---	1.569 ---	54.50	Qth	Orange scoriaceous lapilli.
226	1.570	54.50	Qlh	
MJW-97	1.570	54.50	Qta_2	Greene, 1968. SiO_2 % low?
147 ---	1.573 ---	54.00	Qv_2	
MJW-18	1.574	53.75	Qlf_1	Greene, 1968. Refined value.

(*) Indicates modal analysis. All "MJW" numbers (Greene, 1968) have modal analyses and are included with others in Tables III-XV.